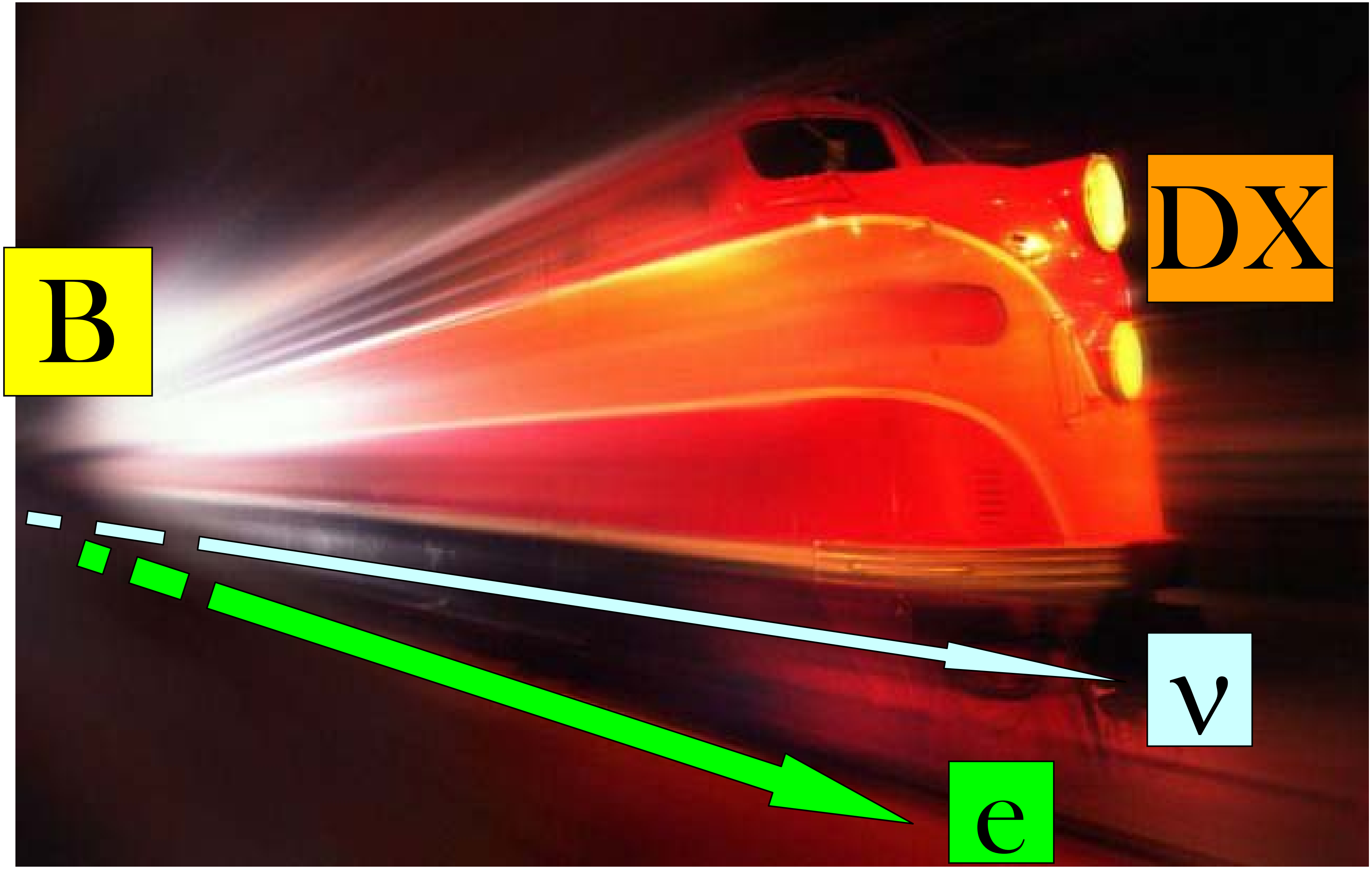
Can we understand $\bar{B} \rightarrow D^{(*)} X \, l \, \nu_l$ decays ?



February 4-6, 2013, Valencia

see also: http://events.lal.in2p3.fr/WorkshopBdecays/

P. Roudeau (thanks to A. Le Yaouanc and D. Becirevic)

Overall picture

Expt.:

$B(B^0 \to X_c\, l\, \nu)$ = (10.09 ± 0.22)% → $B(B^0 \to D\, l\, \nu)$ = (2.12 ± 0.06)%

→ $B(B^0 \to D^*\, l\, \nu)$ = (5.11 ± 0.10)%

→ $B(B^0 \to D_1\, l\, \nu)$ = (0.58 ± 0.05)%

→ $B(B^0 \to D_2^*\, l\, \nu)$ = (0.29 ± 0.03)%

It remains:

$B(B^0 \to X_{c,broad}\, l\, \nu)$ = (2.00 ± 0.26)% → $B(B^0 \to D^{(*)} \pi\, l\, \nu)_{broad}$ = (0.75±0.09)%

→ $B(B^0 \to D^{(*)} x\, l\, \nu)_{broad}$ = (1.24±0.26)%

« x » being more than 1 pion

About 20% of B-meson semileptonic decays are not well understood.

Remaining questions in $B \to D^{(*)} \pi\, l\, \nu_l$

Expt.:

$B(B^0 \to D\, \pi\, l\, \nu)_{broad} = (0.42 \pm 0.06)\%$ ↔ $B(B^0 \to D\, \pi\, l\, \nu)_{narrow} = (0.18 \pm 0.02)\%$

$B(B^0 \to D^*\, \pi\, l\, \nu)_{broad} = (0.33 \pm 0.07)\%$ ↔ $B(B^0 \to D^*\, \pi\, l\, \nu)_{narrow} = (0.50 \pm 0.04)\%$

$B(B^0 \to D_1\, l\, \nu) = (0.58 \pm 0.05)\%$

$B(B^0 \to D_2^*\, l\, \nu) = (0.29 \pm 0.03)\%$

Theory (naïve):

$$B(B^0 \to D_0^*\, l\, \nu) \approx B(B^0 \to D_1'\, l\, \nu) << B(B^0 \to D_1\, l\, \nu) \approx B(B^0 \to D_2^*\, l\, \nu)$$

- If we identify the $(D^{(*)}\, \pi)_{broad}$ final states with the D_0^* and D_1' , then there seems to be a contradiction with theory !

$\tau_{3/2} > \tau_{1/2}$

- Heavy meson Qq; $J = j_q \oplus s_Q$, $j_q = L \oplus s_q$, $s_Q = s_q = ½$

- For L = 1, j_q = 1/2 or 3/2

- The heavy quark spin is decoupled, meson properties depend on j_q

- Adding the heavy quark gives 2 doublets
  - $j_q = 1/2$ → J^P = 0^+, 1^+ broad (D_0^*, D_1), mainly S-wave decays
  - $j_q = 3/2$ → J^P = 1^+, 2^+ narrow (D_1', D_2^*), mainly D-wave decays

-Within a doublet,states (are expected) to have similar properties. Production rates in B decays governed by 2 form factors : $\tau_{1/2}(w)$ and $\tau_{3/2}(w)$, $w = v_B.v_D$ (in the infinite mass limit).

$\tau_{3/2}(1) \simeq 0.54\,, \qquad \tau_{1/2}(1) \simeq 0.22$ Quark model

$\tau_{3/2}(1) = 0.528(23)\,, \qquad \tau_{1/2}(1) = 0.297(26)$ LQCD

B(B^0→$\mathbf{D_{3/2,1/2}}$ **l** ν) depend on:

$\tau_{3/2}^2(1)/\ \tau_{1/2}^2(1)$	~ 3 - 6
slope of ff. versus w	~ 0.7
decay rate expression (spin)	~ 2.2
Total:	5 - 9

-Need better evaluation of uncert. and of other effects as finite mass corrections

The $B \to D \pi l \nu_l$ decay channel

Expt.:

$B(B^0 \to D \pi l \nu)_{broad} = (0.42 \pm 0.06)\%$ ↔ $B(B^0 \to D \pi l \nu)_{narrow} = (0.18 \pm 0.02)\%$

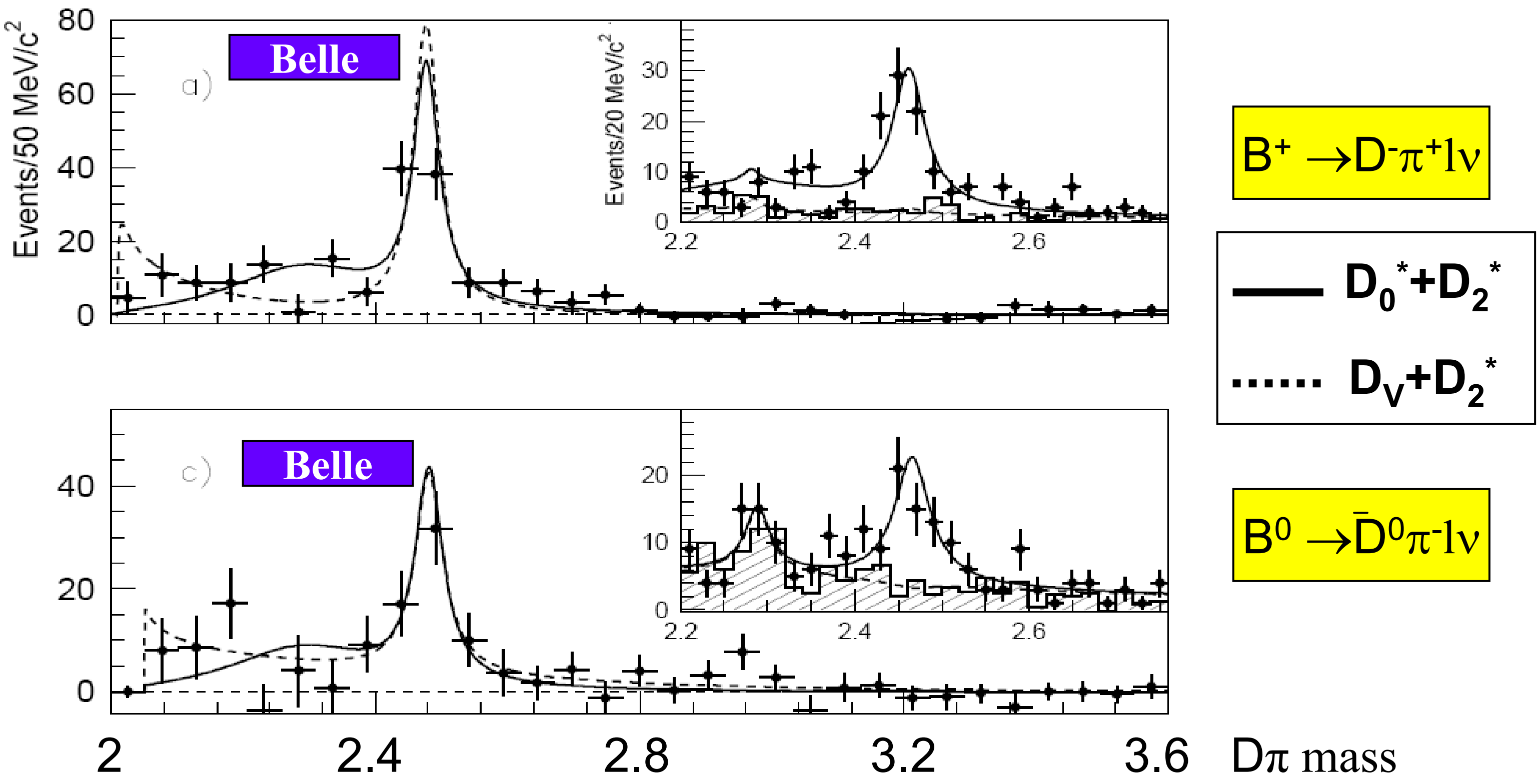
Belle analysis:	**Babar analysis:**
$B(B^0 \to D_0^* l \nu) = (0.30 \pm 0.10 \pm 0.07)\%$	$(0.66 \pm 0.12 \pm 0.09)\%$
$B(B^- \to D_0^* l \nu) = (0.36 \pm 0.06 \pm 0.09)\%$	$(0.39 \pm 0.08 \pm 0.06)\%$

HFAG average:

$B(B^0 \to D_0^* l \nu) = (0.40 \pm 0.08)\%$

- Compatible results between BaBar and Belle
- The D_0^* can account for all the $(D \pi)_{broad}$ component but uncert. are large
- In practice there are differences between the 2 analyses.

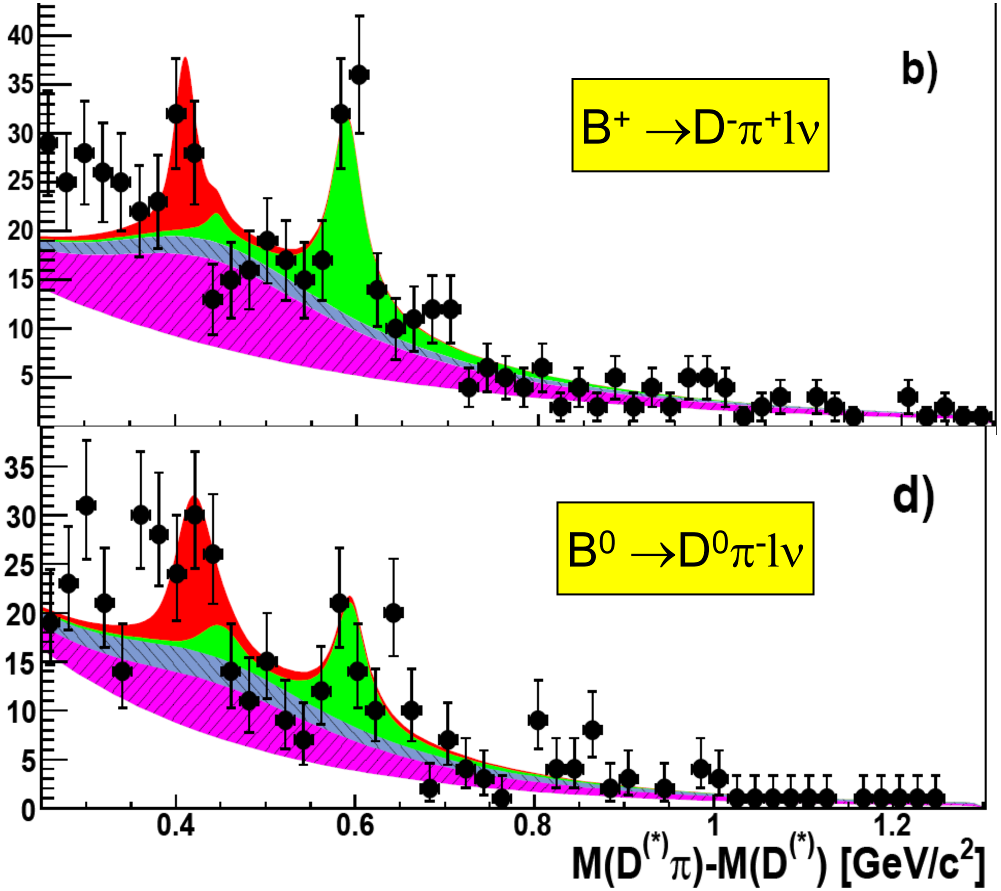
Belle analysis

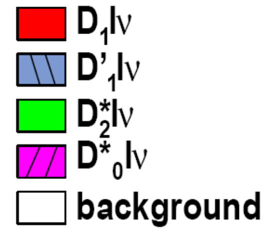


-D_0^*+D_2^* favoured over D_V+D_2^* by 2.8 sigmas

- and background $D^{(*)}\pi$ mass spectra. The signal function includes all orbitally excited D^{**} contributing to the given final state (D_0 and D_2^* to $D\pi$ and D_1, D_1', D_2^* to $D^*\pi$), each of which is described by a relativistic Breit-Wigner function for a known orbital momenta, and a non-resonant part described by the Goity-Roberts model [16]. D^{**} masses and widths are

Babar analysis





Larger window on $mm^2(\nu)$ than in Belle (keeps soft π).

Excess of evts at low mass attributed to D nπ l ν_l not included in the simulation.

- resonances do not include « Goity-Roberts » effects
- fitted model assumes only D** states

Comments on present analyses

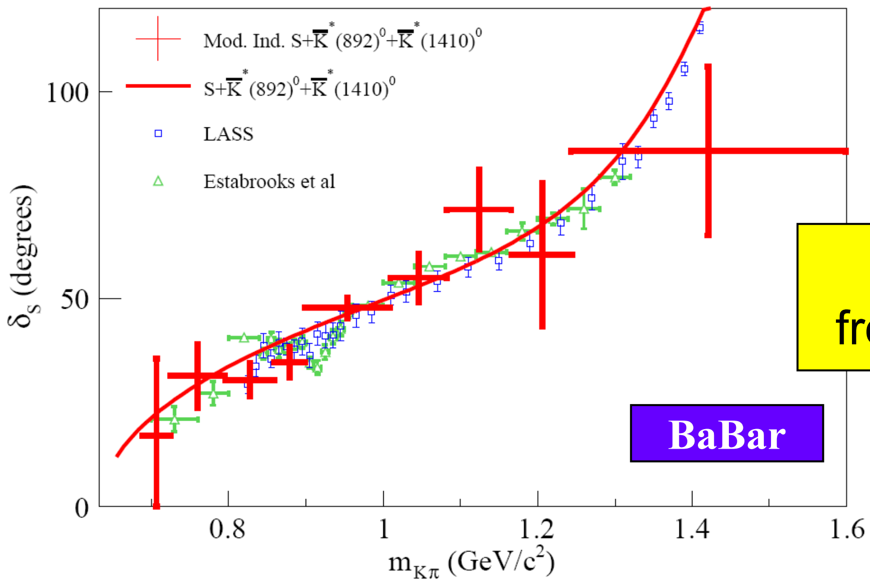
- Agreement between BaBar and Belle is a bit « artificial »

-There seems to be an excess of evts at low mass :
“à la Goity-Roberts”? D_V*?

- Most probably the D_0* is only a fraction of the (**D** π) **broad**

- What is the equivalent of the K_0*(800) for charm ?

- Radial excitations?



S-wave phase
from $D^+ \to K^- \pi^+ e^+ \nu_e$

What can be done ?

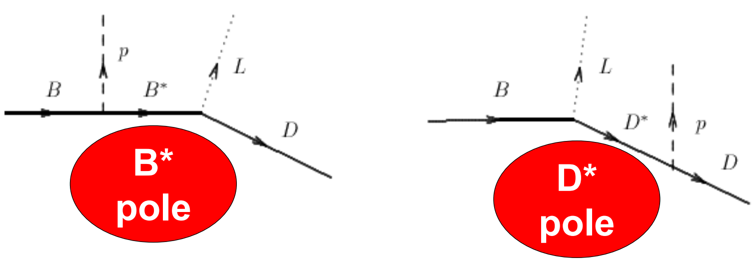
-Get expressions from theorists for $dB(B^0 \rightarrow \mathbf{D}\ \pi\ \mathbf{l}\ \nu)$ **/dx⁵**
(tests can be done on $D^+ \rightarrow K^-\pi^+ e^+\nu_e$?)

- Can one normalize the D* (B*) pole contribution(s) ?

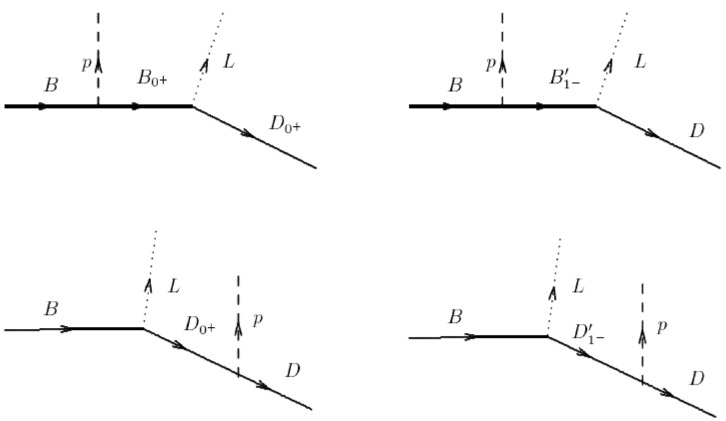
- Use $B^0 \rightarrow D\pi\pi$, which has larger statistics, to understand the $(\mathbf{D}\ \pi)_{\mathbf{broad}}$ components ← **LHCb**

- Use $B^- \rightarrow D^+\pi^-\pi^-$ to measure the phase of the $D_0^* \rightarrow D\pi$ versus the $D\pi$ mass. ← **LHCb**

- Have new spectra from BaBar with similar cuts as in Belle

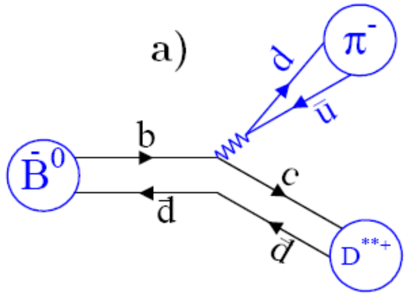


NR contributions in $B \rightarrow \mathbf{D}\ \pi\ \mathbf{l}\ \nu$ decays



Resonant contributions

$\bar{B}^0 \rightarrow D^0 \pi^+ \pi^-$



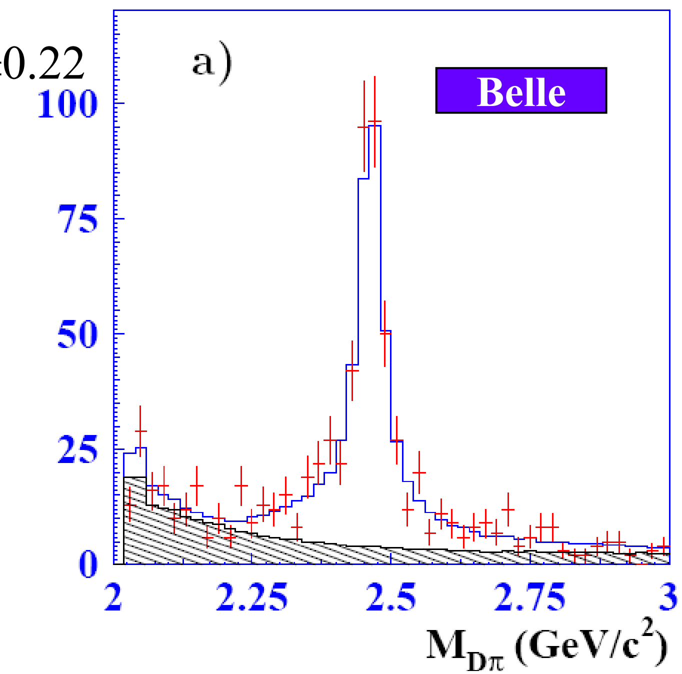
Type I decay, can be related to sl. decay at $q^2 = m_\pi^2 \sim 0$, using factorization

Results from Belle (published) and BaBar (prelim.) are not in nice agreement.

Belle

$\mathcal{B}_{B\to D_0^*\pi}\mathcal{B}_{D_0^*\to D\pi}(10^{-4})$	$0.60 \pm 0.13 \pm 0.15 \pm 0.22$
$\phi_{D_0^*}$	-3.00 ± 0.13
$M_{D_0^*}, (MeV/c^2)$	2308.0
$\Gamma_{D_0^*}, (MeV/c^2)$	276.0
$\mathcal{B}_{B\to D_v^*\pi}\mathcal{B}_{D_v^*\to D\pi}(10^{-4})$	0.88 ± 0.13
$\phi_{D_v^*}$	-2.62 ± 0.15

- significant $D_V{}^*$ component
- LHCb can improve the accuracy
- difficult analysis



$\overline{B}^0 \rightarrow D^{0(*)}\pi^+\pi^-$

$B_d^0 \rightarrow \overline{D}^{**}\pi^+$	theory	expt.
$\overline{D}_2^*$	1.1×10^{-3}	$(0.49 \pm 0.07) \times 10^{-3}$
$\overline{D}_1$	1.3×10^{-3}	$(8.2^{+2.5}_{-1.7}) \times 10^{-4}$
$\overline{D}_1'$	1.1×10^{-4}	$< 10^{-4} (90\%\ C.L.)$
$\overline{D}_0^*$	1.3×10^{-4}	$[0.3, 3.4] \times 10^{-4}$

$B_d^0 \rightarrow \overline{D}^{**} e^+\nu_e$		
$\overline{D}_2^*$	0.7×10^{-2}	$(0.29 \pm 0.03) \times 10^{-2}$
$\overline{D}_1$	0.45×10^{-2}	$(0.58 \pm 0.05) \times 10^{-2}$
$\overline{D}_1'$	0.7×10^{-3}	$[0., 3.2] \times 10^{-3}$
$\overline{D}_0^*$	0.6×10^{-3}	$(3.5 \pm 0.7) \times 10^{-3}$

Need better accuracy

- theory uncertainties ?

- rough agreement between th. and expt. in nl decays and for narrow states in sl. decays

- disagreement for broad states in sl. decays

$B^0_s \to D_{0s}^{*-}\pi^+$, $D_{0s}^{*-} \to D_s^- \pi^0$

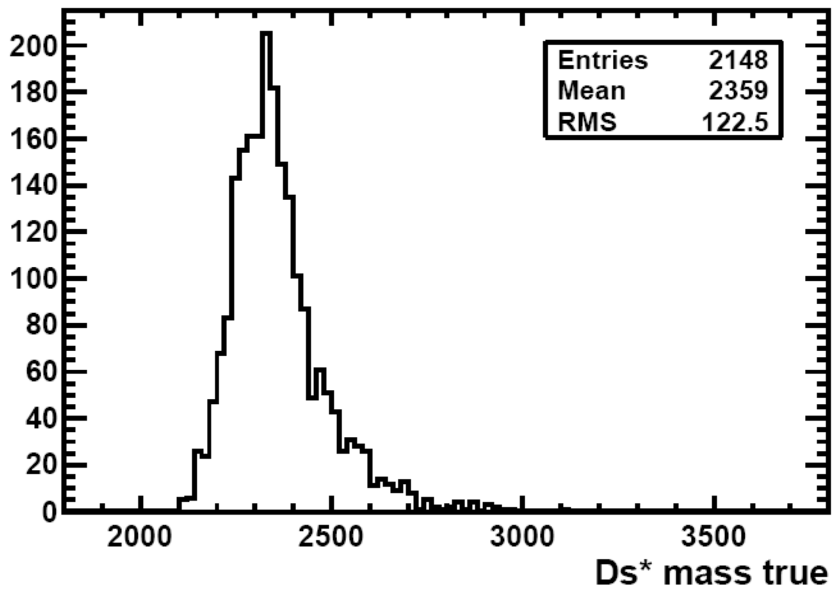
- This is a type I diagram

- The D_{0s}^{*-} is very narrow (avoid the problem of measuring broad states)

- … unfortunately needs to reconstruct a soft π^0 (missed ?)

- so … signal expected to be relatively broad
(use of kinematic constraints at LHCb)

LHCb

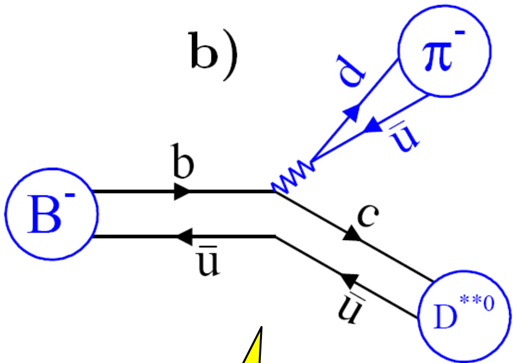


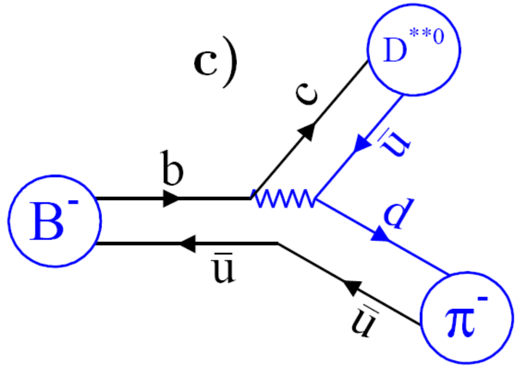
- expect few hundred evts/ fb^{-1}

- background level ?

[c.f. arXiv:1206.5869 [hep-ph]]

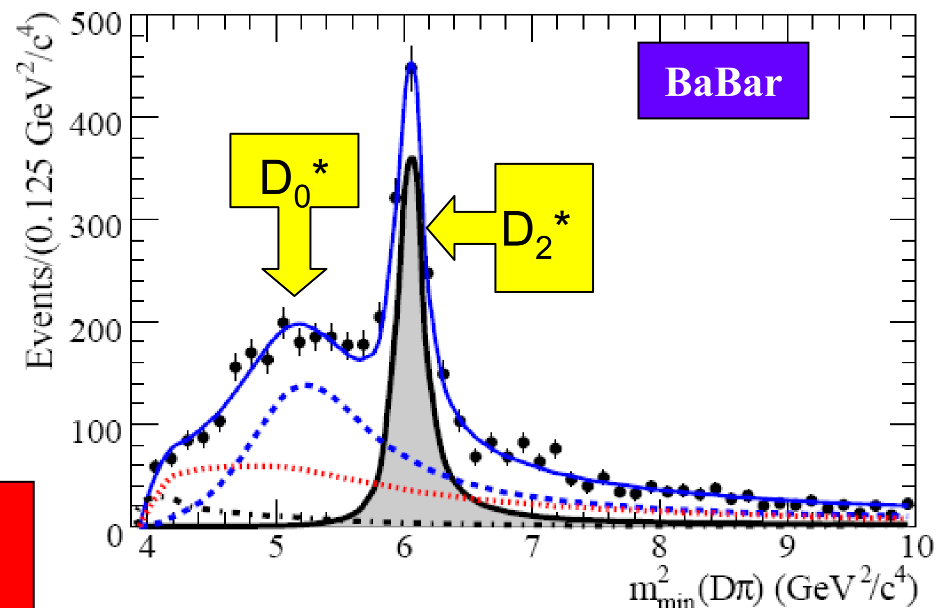
$B^- \to D^+ \pi \pi$





Type III decay, can be be used to measure the Dπ S-wave phase

Is the D_0* a simple Breit-Wigner?



- large signal, rather small backg.

- LHCb can improve the accuracy

LHCb

The B → D* π l ν_l decay channel

Expt.:

B(B^0→**D*** π **l** ν) **broad** = **(0.33 ± 0.07)%** ↔ B(B^0→**D*** π **l** ν) **narrow** = **(0.50 ± 0.04)%**

Belle analysis:

B(B^-→**D_1' l** ν) = (–0.04 ±0.08 ±0.10)%

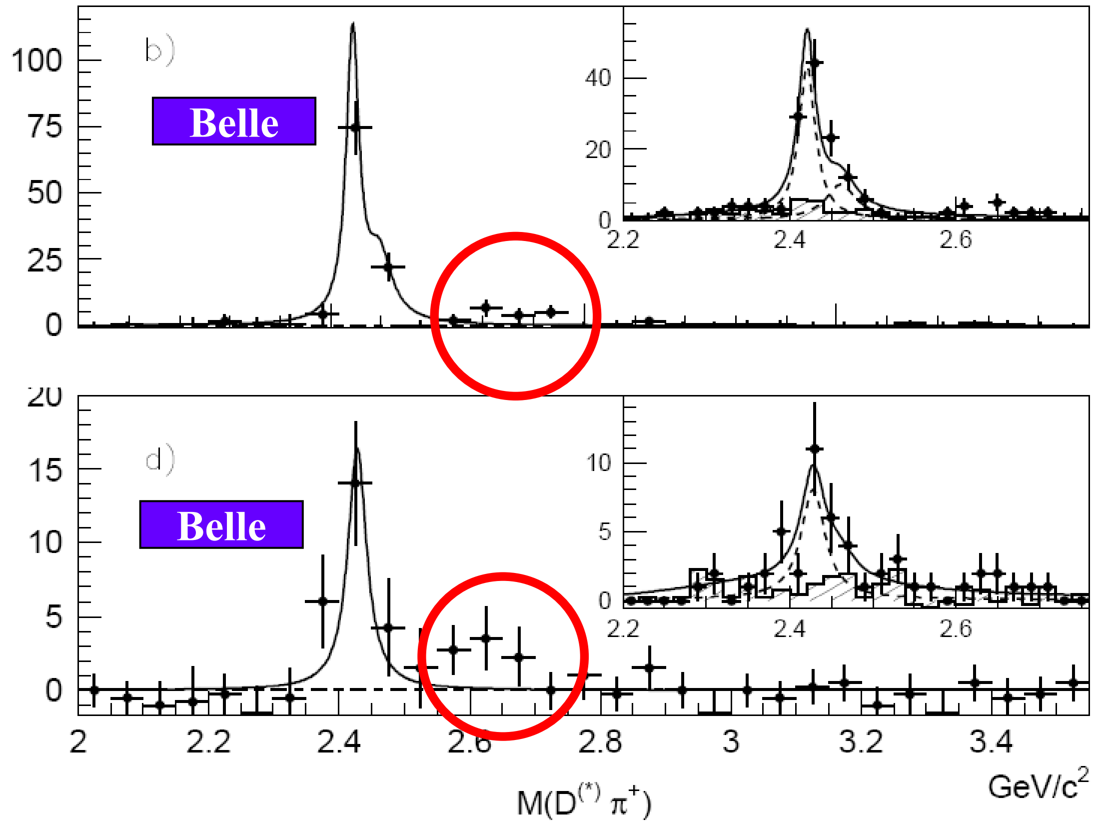
Babar analysis:

(0.38 ±0.06 ±0.06)%

HFAG average: ??

- **BaBar and Belle not in « good » agreement (~ 3 σ)**
- **Can BaBar tighten the cuts on** $mm^2(\nu)$?

Belle analysis

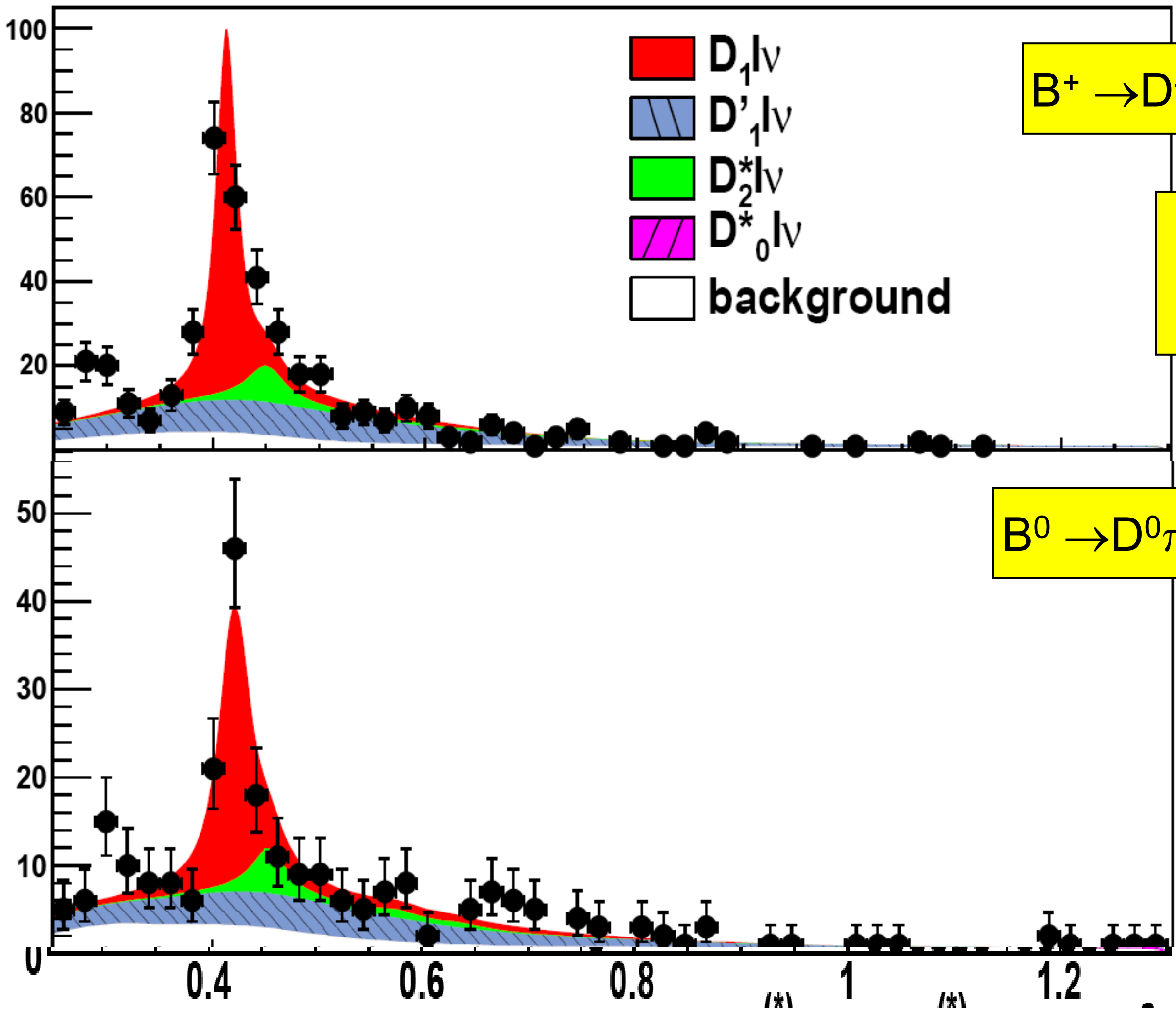


$B^+ \rightarrow D^{*-}\pi^+ l\nu$

$\overline{B}^0 \rightarrow D^{*0}\pi^- l\nu$

- no evidence for D_1'
- some « excess » around 2.6 GeV ?

Babar analysis



$B^+ \to D^- \pi^+ l\nu$

Larger window on $mm^2(\nu)$ than in Belle (keeps soft π).

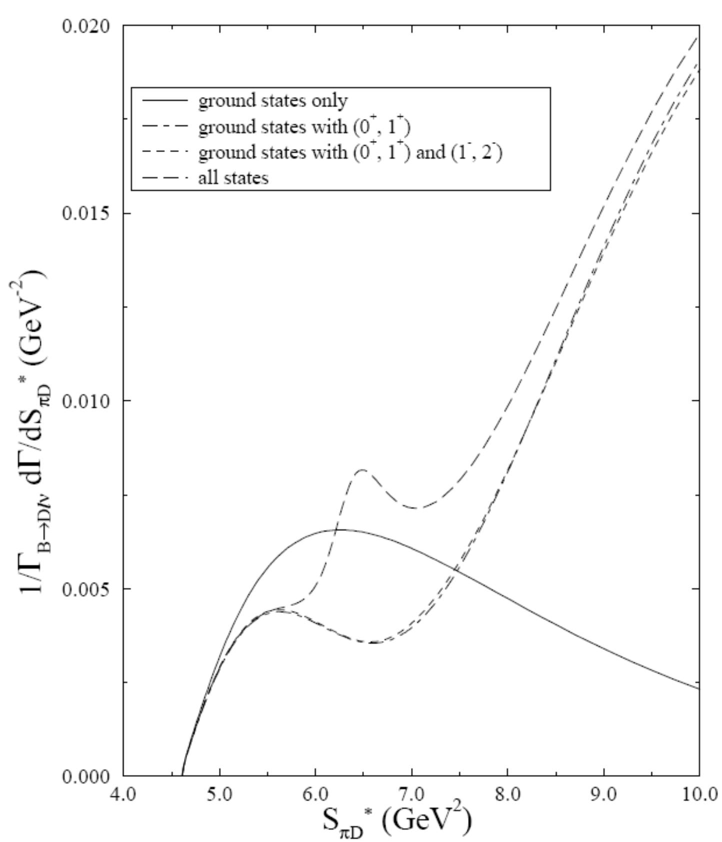
$B^0 \to D^0 \pi^- l\nu$

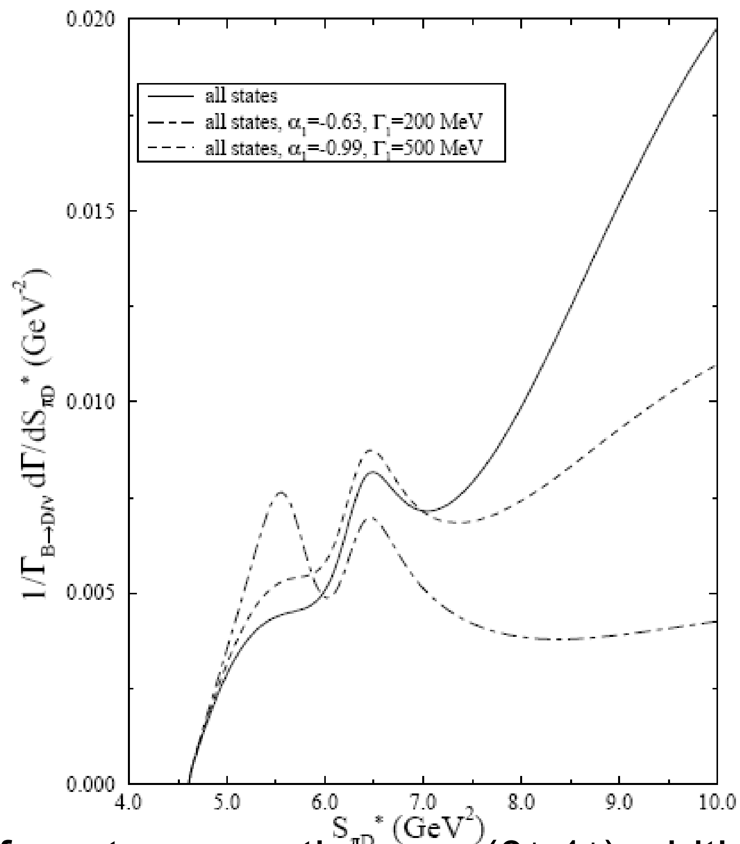
- no spectacular excess around m(D*) + 0.6 GeV

Comments on present analyses

- Poor agreement between BaBar and Belle

-The "Goity-Roberts" model predicts contributions at high masses (validity?), what about (1^-,2^-) ? The non-resonant component is expected to be large … normally it can be absolutely normalized!





With different assumptions on (0^+,1^+) width

Radial excitations

State	decay		Final state	Angular mom.
D'(2550) **$J^P=0^-$** **M=2540 MeV** **Γ=130 MeV**	**$D\pi$** **$D^*\pi$** **$D_0^*(2400)\pi$** **$D_1\,\pi$** **$D_2^*(2460)\pi$**	**No** **Yes** **Yes** **No** **Yes**	 **$D^*\pi$** **$D\pi\pi$** **$D\pi\pi$, $D^*\pi\pi$**	 **L=1** **L=0** **L=2**
D*'(2600) **$J^P=1^-$** **M=2610 MeV** **Γ=93 MeV**	**$D\pi$** **$D^*\pi$** **$D_0^*(2400)\pi$** **$D_1\,\pi$** **$D_2^*(2460)\pi$**	**Yes** **Yes** **No** **Yes** **Yes**	**$D\pi$** **$D^*\pi$** **$D^*\pi\pi$, $D\pi\pi\pi$** **$D\pi\pi$, $D^*\pi\pi$**	**L=1** **L=1** **L=0** **L=2**

- Relatively narrow

- L=0 or 1 presumably dominant

BaBar

$B(D\pi) / B(D^*\pi) = 0.32 \pm 0.02 \pm 0.09$

Production rates in cc events

State	Efficiency (%)	Yield ($x10^{-3}$)	Yield corrected ($x10^{-7}$)
$D_1(2420)^0$	**1.09±0.03**	**214.6±1.2±6.4**	**4.38±0.13±0.19**
$D_2^*(2460)^0$	**1.12±0.04**	**136±2±13**	**4.67±0.45±0.36**
$D'(2550)^0$	**1.14±0.04**	**98.4±8.2±38**	**(1.3±0.5)/** $\alpha(D')$
$D^{*\prime}(2600)^0$	**1.18±0.05**	**71.4±1.7±7.3**	**(0.9±0.1)/** $\alpha(D^{*\prime})$

BaBar

Final state measured: $D^{*+}\pi^-$

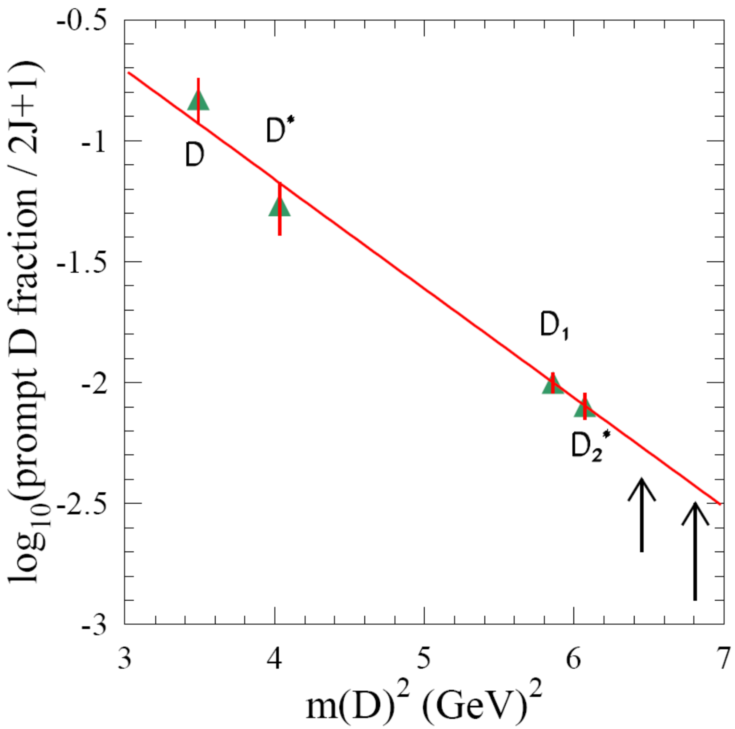
Yield corrected values assume:
- $B(D_1(2420)^0 \rightarrow D^{*+}\pi^-) = 0.45 \pm 0.02$
- $B(D_2^*(2460)^0 \rightarrow D^{*+}\pi^-) = 0.26 \pm 0.02$
- $B(D' / D^{*\prime})^0 \rightarrow D^{*+}\pi^-) = 2/3 \times \alpha$

-α is the fraction of decays into the $D^*\pi$ final state.

LEP recollections …

Particle prod. in jets can be described using:
$(2J+1) \times \exp(-b\, m^2)$

$P(c \to D_1(2420)) \sim 3\ \%$



- **$P(c \to D') \sim 0.5\%$**
- **$P(c \to D^{*\prime}) \sim 1.1\ \%$**

- $\alpha(D') = 1.6 \pm 0.6$ .. rather uncertain
- $\alpha(D^{*\prime}) = 0.5 \pm 0.1$

Rather large decay rates of D' and $D^{*\prime}$ into $D^*\pi$!

What about B sl decays ?

Can we explain broad D(*)π components in $B^0 \to D^{(*)}\pi l \nu_l$ by the $D^{(*)}$' ?

	(%)
$B_d^0 \to D_1^- \ell^+ \nu_\ell$	0.58 ± 0.05
$B_d^0 \to D_2^{*-} \ell^+ \nu_\ell$	0.29 ± 0.03
$B_d^0 \to [\overline{D}\pi]_{broad} \ell^+ \nu_\ell$	0.42 ± 0.06
$B_d^0 \to [\overline{D}^*\pi]_{broad} \ell^+ \nu_\ell$	0.33 ± 0.07

One expects that $D^{(*)}$'states are less abundant than narrow D** because they have a higher mass (to be checked: decay rate expressions, form factors, …)

- only the D*' can contribute to Dπ (broad)
- upper limit: 0.6 % x ½ x 0.3 ~ 0.1 %

The D*' has a negligible effect in Dπ broad.

- for D*π (broad) there could be $D^{(*)}$' contributions.
- my guess estimate: <0.1% from D', ~ 0.1% from D*' … could be enough

- for $D^{(*)}\pi\pi$ (broad) my guess estimate:
<0.1% from D', ~ 0.1% from D*' … this cannot explain the 1.25±0.25 %

$B \to D^{(*)} X\, l\, \nu_l,\ X \neq \pi$

Expt.:
$B(B^0 \to D^{(*)}\, x\, l\, \nu)_{broad} = (1.24 \pm 0.26)\%$; « x » being more than 1 pion
$B(B^0 \to D\pi\pi\, l\, \nu)_{narrow} = (0.19 \pm 0.02)\%$; from D_1
$B(B^0 \to D_s^{(*)} K^0\, l\, \nu) = (0.06 \pm 0.01)\%$

What are these states?

- Can be explained by radial excitations?
  - Yes → **Phys.Rev. D85 (2012) 094033**
  - No → see previous discussion, expect 0.1% contribution
  - ? → large signal expected in nl: **arXiV:1301.7336**

- NR contributions ? $(1^-, 2^-)$ resonances ? « à la Goity-Roberts »

- $X = \eta$: expect small rates

- Decays of broad D** states into $D^{(*)}\pi\pi$? (small)

Conclusions

- from nl B^0 decays, broad D** are disfavoured relative to narrow states (uncert. are still large)

- in $B^0 \rightarrow D\ \pi|_{broad}\ l\ \nu$: D_0^* is non negligible and a NR component at low mass is likely

-in $B^0 \rightarrow D^*\ \pi|_{broad}\ l\ \nu$: D1' is expected to be similar as the D_0^* (?), possibly a small radial component

- need ideas and theory input to describe $B^0 \rightarrow D\ \pi\pi|_{broad}\ l\ \nu$ decays (NR, radial excitations?, D-waves, ….)

LHCb can provide informations analyzing nl. $B^- \rightarrow D^{+(*)}\ \pi^-\pi^-$, $B^0 \rightarrow D^{0(*)}\ \pi^+\pi^-$ and $B^0_s \rightarrow D_{0s}^{*-}\pi^+$.

Maybe also LHCb can analyze sl. B decays to search for radial excitations mass peaks in $D^{(*)}\pi$ mass distributions.