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Waiting for Truths and Analyzing Facts in $B \rightarrow l \nu X_c$

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OPE has been applied to $B \rightarrow l \nu X_c$
- total width and moments -
with considerable success leading to a high accuracy description of high quality data:
$\Delta|V(bc)| = \pm 2\ \%$
Essential foundations of success story:

- heavy quark symmetry
- $1/m_Q$ expansions

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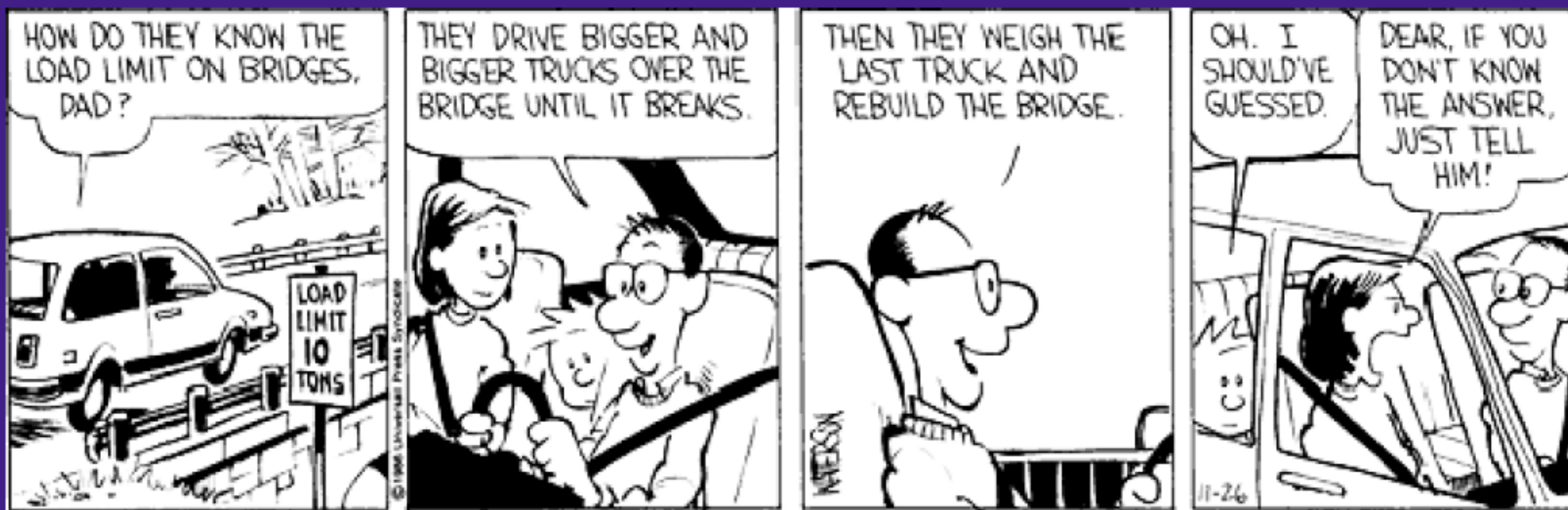

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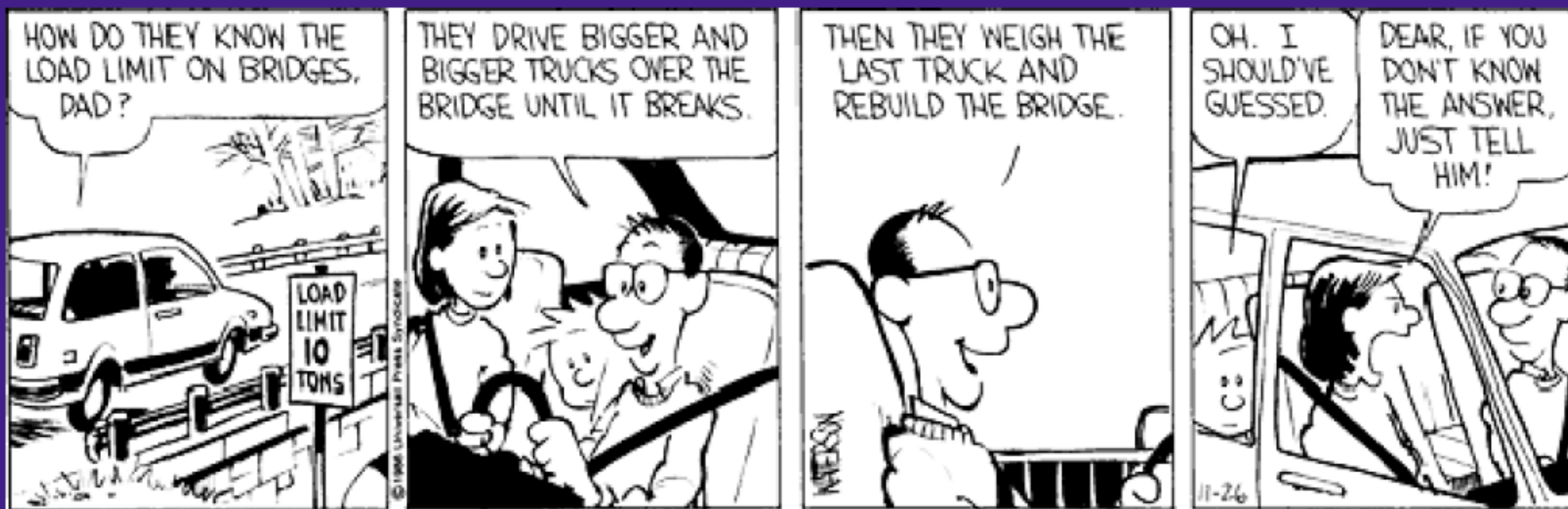

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One applies a theoretical framework/technology to more and more processes & observables – till it fails!

Heavy Quark Symmetry & Heavy Quark Expans.

$\sim H_{Pauli} = - A_0 + (i\partial - \mathbf{A})^2/2m_Q + \sigma\cdot\mathbf{B}/2m_Q \rightarrow - A_0$ as $m_Q \rightarrow \infty$

i.e.,
infinitely heavy static quark, without spin dynamics,
only colour Coulomb potential!

- hadrons H_Q labeled by total spin S and by $j_q = l_q + s_q$:
  - ground states: $[S|l_q|j_q] = [0,1|0|1/2]$:
    PS -- B or D -- & V -- B* or D*
  - 1st excit. states: [0,1|1|1/2] & [1,2 |1|3/2]

  4 P wave states: 2 $j_q=3/2$ narrow states
  2 $j_q=1/2$ broad states

m_Q : m_b or m_c, yet $1/m_b < 1/m_c$!

(2/3 - 3/4) of $B \to l\nu X_c$ given by D/D*

- ➥ charm can act as a heavy flavour
- HQS classification used also for charm!
  - more dubious for higher excitations

✍ what is the rest of X_c made up from?

- P wave states will be present and more

$D^{**} = X_c - (D+D^*)$
- $= D_{1/2,3/2}$, $l > 1$ & radial excitations
- = non-resonant $D/D^* + \pi$'s configurations

\`OPE machinery' leads to various Heavy Quark Sum Rules

$$\mu_\pi^2(\mu)/3 = \Sigma_n^{\varepsilon<\mu}(\varepsilon_{1/2}^{(n)})^2|\tau_{1/2}^{(n)}(1)|^2 + 2\,\Sigma_m^{\varepsilon<\mu}(\varepsilon_{1/2}^{(n)})^2|\tau_{3/2}^{(m)}(1)|^2$$

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- no accurate mass predictions
  1/2 P waves could be lighter or heavier than 3/2 P waves
- no reliable predictions on decay patterns

analysis of HQ SR
using observed values of HQP &
assuming expected (approximate) saturation
yields for P wave production

$\varepsilon_{1/2}^{(0)} \sim (300 - 500)$ MeV vs. $\varepsilon_{3/2}^{(0)} \sim 450$ MeV

$\tau_{1/2}^{(0)}(1) \sim 0.14 - 0.32$ vs. $\tau_{1/2}^{(0)}(1) \sim 0.6$

narrow `3/2' have to dominate over broad `1/2'

Quark Models – BT model:

satisfies HQS, Bjorken and Spin SRs, yet no $1/m_c$ correction

- `3/2' > `1/2'

LQCD -- yet no $1/m_c$ correction

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  unconventional scenarios: radial excitations?
  - 2 structures 0^-, 1^- vs. 0^+, 1^+ for P waves

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$$D^{(n)} \rightarrow D/D^{*}+\eta \, ?$$

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- Most valuable analogy will be $B_s \to l \nu D_s(*)\pi$'s etc.; finding $B \to l \nu D_s K$ would be a `game changer'

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    - novel lessons on non-perturbative dynamics
    - even of practical concerns – will affect in particular values of integrated moments!