Go back to 2006:

The Physics of Beauty (& Charm[& τ])
in the Era of the LHC

Ikaros Bigi, Notre Dame du Lac

7/' 06

Jagiellonian University = Founding & Elite Member of Academia

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N. Uraltsev: “The Heavy Quark Expansion”,
Symposium on Radiative Corrections (CRAD96),
arXiv:hep-ph/9612349,
Acta Phys.Polon. B28 (1997) 755
N. Uraltsev: “Topics in the Heavy Quark Expansion”,
arXiv:hep-ph/0010328

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The Dynamics of Beauty & Charm Hadrons & top quarks in the Era of the LHCb & Belle II & ATLAS/CMS Motto: Non-perturbative QCD & Many-body Final States

Ikaros Bigi, Notre Dame du Lac

Jan. 9 – 12/2018

Epiphany = επιφανεια .

[El Greco]

[Tintoretto]

Epiphany = manifestation of a divine being
an intuitive grasp of reality through
something both simple & striking --

The Dynamics of Beauty & Charm Hadrons & top quarks in the Era of the LHCb & Belle II & ATLAS/CMS

Motto: Non-perturbative QCD & Many-body Final States

Ikaros Bigi, Notre Dame du Lac

Jan. 9 – 12/2018

Epiphany = επιφανεια .
Best `fitted' analyses of the data ?
correlations & judgments !

[El Greco]

[Tintoretto]

Epiphany = manifestation of a divine being
an intuitive grasp of reality through something both simple & striking –
however, it is *not* here.

General Comments:

(A) Anomalies – "deep" or not so
(B) *Wilsonian* Operator Product Expansion
(C) Infrared Renormalon with non-perturbative QCD

`Stuff' with some details

(I) (Consistent) Parameterization of the CKM Matrix
(II) Definitions of Quark Masses:"MS","kinetic",`1S',`pole mass'
(III) V_{qb} [q=c,u]: exclusive vs. inclusive rates and duality
(IV) Broken U- & V-spin symmetries
(V) *3- & 4-body* Final States in Beauty & Charm Mesons
(VI) Challenges for Beauty & Charm *Baryons*
(VII) The Stage of top quarks - in a Search for New Dynamics
(VIII) Needed Collaboration of HEP & MEP/Hadrodynamics

(A) Anomalies – "deep" or not so

The word `anomalies' is often used in the literature –
in particular,
when one looks for the impact of New Dynamics (ND).
It is easier to discuss exclusive semi-leptonic transitions.
However, the situation is `complex' to put it politely.

(A1) "Deep anomaly"

"Quantum anomaly" (`$U(1)_A$ problem'): classical symmetry – in this case chiral invariance for massless quarks – is no longer conserved, once one-loop corrections are included:

$$\delta_\mu J_\mu^{(5)} = (\alpha_S/8\pi)\, \tilde{G} \,.\, G \; (+\, m_q \overline{\psi} \gamma_5 \psi)$$

"triangle anomaly": *not renormalizable* in 4-ε dimensions
SM `deal' with that by connecting the
world of quarks & charged leptons (i.e., 3 colors) –
but there must be a deep reason for that!

(A2) Maybe anomaly

Differences in expectations vs. present data;
example[s]: B -> l^+l^- K^*[/ρ]
-- SM predicts tiny rates & M[l^+l^-] ≠ 0 outside resonance K^*
-- it is said data show more events than expected with ~ 3 σ -- sign of ND?
-- Maybe an anomaly with more data leading to 5 σ ?

(A2) Maybe anomaly

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-- Maybe an anomaly with more data leading to 5 σ ?

-- First analogue in history:

after losing the battle of Albuera in 1811 Marechal Soult said:
"I had beaten the British -- it was just they did not know when they were beaten." He was right on both counts ...

-- Maybe the impact of strong re-scattering in the world of quarks (& gluons):

$[s\ \bar{q}]$ -> K + π's, 3 K

(B) *Wilsonian* Operator Product Expansion

"not all OPE's are created equally !"
almost all invoke OPE -- but often without using
Wilsonian prescription

Shifman (& collaborators) had emphasized that applying OPE is subtle, namely in the *Wilsonian* OPE that *stops* at ~ 1 GeV, not lower.
It is one thing to draw diagrams, while another thing is understand the underlying dynamics –
in particular non-perturbative QCD with some accuracy.

I will come back below (& later) about the *definition* of quark masses: *Infrared Renormalon*

(C) Infrared Renormalon

In 1952 *Dyson* pointed out that amplitudes cannot be convergent in perturb. theory of QED. Later it was realized that perturb. series in a QFT are factorially divergent.
Instead of asymptotic series one can introduce a Borel transform B_Z; thus it is convergent provided that B_Z has no singularities on the real positive semi-axis in the complex plane. That is fine for QED.

(C) Infrared Renormalon with non-perturbative QCD

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If it has a singularity, it meaning become ambiguous; one needs more information about the underlying dynamics.

Now look at QCD (Shifman *et al.*: contribution to
"QCD & Heavy Quarks – In Memoriam Nikolai Uraltsev").

Good side: strong couplings go down to zero: "asymptotic freedom".
Yet:
the couplings are strong a low scales μ~1 GeV on perturb. QCD.

Short comments about the definition of the *top quark mass* later -- it is subtle!

(C) Infrared Renormalon with non-perturbative QCD

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IR renormalons in QCD are *not* Borel summable in a perturbative series.
IR contributions leads to an intrinsic uncertainty in the *pole* mass – i.e., Λ/m_Q power correction.
Those give contributions numerically:

$$m_b^{pole} = m_b(1\text{ GeV}) + \delta m_{pert.}(< 1\text{ GeV}) \sim 4.55\text{ GeV} + 0.25\text{ GeV} + 0.22\text{ GeV} + 0.38\text{ GeV} + 1\text{ GeV} + 3.3\text{ GeV} + \ldots$$

It is crucial to use *Wilsonian* OPE as much as possible!

(I) Parameterization of the CKM Matrix

(I.1) Wolfenstein's parameterization

Wolfenstein's parameterization was very smart, easily usable, well-known & used all the time. The SM with 3 families of quarks describes the CKM matrix with 4 parameters: λ, A, ρ, η;
expansion of λ = 0.223, while A, ρ, η are $\mathcal{O}(1)$.

(I.1.1) Maximal CP asymmetry ?!

It is an important item (in particular about finding the impact of ND), but a subtle one: What does one mean by `maximal CPV'?
Short comments based on an example: Wolfenstein's parameterization:
-- 100 % asymmetry in principle.
-- a few examples in the landscape: ρ =1, η =-1 ; ρ = -1, η ~ 3.5/-0.5 ;
ρ =-1/2, η ~ 2.5/-0.3.
- it could work.

(I.1.2) `Real' world

Measured values: $A \approx 0.82$; however: $\eta \approx 0.35$, $\rho \approx 0.14$ not close to unity;
thus not real control over *systematic* uncertainties.

(I) Parameterization of the CKM Matrix

(I.2) *Consistent* parameterization

Need *consistent* parameterization of CKM matrix with more precision [Y.H. Ahn, H-Y. Cheng, S. Oh (2011)] through $\mathcal{O}(\lambda^6)$!

$$\begin{bmatrix} 1-\lambda^2/2-\lambda^4/8-\lambda^6/16 & , \quad \lambda & h\lambda^4\exp(-i\delta_{QM}) \\ -\lambda+\lambda^5 f^2/2 & , \quad 1-\lambda^2/2-\lambda^4/8(1+4f^2)-fh\lambda^5\exp(-i\delta_{QM})+\ldots & , \quad f\lambda^2+h\lambda^3\exp(-i\delta_{QM})+\ldots \\ f\lambda^3 & , \quad -f\lambda^2-h\lambda^3\exp(-i\delta_{QM})+\ldots & , \quad 1-\lambda^4/2\, f^2 - fh\lambda^5\exp(-i\delta_{QM})+\ldots \end{bmatrix}$$

with $f \sim 0.75$, $h \sim 1.35$, $\delta_{QM} \sim 90^o$

Pattern is not so obvious as before,

- -- needs more accuracy
- -- deeper insights in flavor dynamics & QCD impacts
- -- correlations between 4 triangles, *not* focus `golden one'
  - maximal SM value for $S(B^0 \to \psi K_S) \sim 0.74$ for indirect CPV
  - SM value $S(B_s^0 \to \psi\phi) \sim 0.03 - 0.05$
  - basically zero CPV for double Cabibbo suppressed decays

(II) Definitions of Quark Masses: "$\overline{MS}$", "kinetic", `1S', `pole mass'

-- With perturbative theory one applies a Green function for a free fermion field with $G(p,\mu) = 1/(\not{p} - m_f(\mu))$
-- the pole mass (or a cut) of the *electron* is very good for a scale μ=0: it is gauge independent and measurable by experiments (although *using* it is not trivial already).
-- The situations are very different for b,c,s,d,u due to confinement to produce hadrons in the initial & final states.
-- Pole mass is gauge independent; furthermore, it is *perturbative* infrared in QCD.

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-- Pole mass is gauge independent; furthermore, it is *perturbative* infrared in QCD.
However, it is *not* infrared stable *non-perturbatively*.

-- It is easy to apply pole mass in Feynman graphs.
Yet pole mass depend on long distance dynamics, for what we have little control.

-- One cannot ignore the impact of renormalons.

(II) Definitions of Quark Masses: "$\overline{MS}$", "kinetic", `1S', `pole mass'

-- "$\overline{MS}$" (`modified minimal subtraction scheme'):
for $\mu > m_Q$ basically coincides with the running mass to describe their *production*.
However, it *diverges* logarithmically for $\mu \to 0$.

The landscape is very different from the *weak decays* of H_Q.
-- the `kinetic scheme' regular in the IR region is the best
$dm^{kin}_Q(\mu)/d\mu = -(16\alpha_S/9\pi) - (4\alpha_S/3\pi)(\mu/m_Q) + \ldots$

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-- recent PDG reviews basically ignore `kinetic scheme', while focus in the `1S scheme' with $m_b^{1S} \approx M_{Y(1S)}/2$

`par ordre du mufti' (= no right of appeal)

- It claims these schemes give us the same information about underlying dynamics -- however, it is incorrect!
  - Uraltsev pointed out: $m_b^{1S} = m_b^{pole}[1 - C_F^2(\alpha_S^2/\pi) +/- \ldots]$
    also m_b^{1S} is *not* well-defined at the *non-perturb.* level

-- The situation is somewhat different for top quarks; I will come back to that below.

(III) V_{qb} [q=c,u]: exclusive vs. inclusive rates and duality

-- it seems the difference between exclusive vs. inclusive in semi-leptonic decays for V_{cb} is smaller now

-- the difference between exclusive vs. inclusive for V_{ub} has not changed;
-- however, has been probed with $B \to l\ \nu\ \pi$'s

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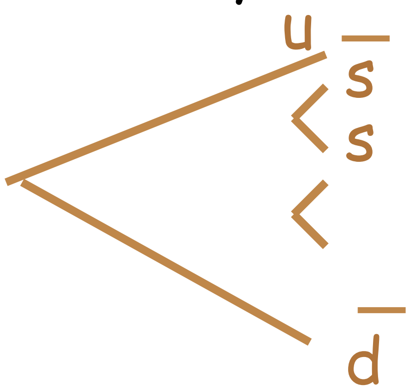
-- the difference between exclusive vs. inclusive for V_{ub} has not changed;
  -- however, has been probed with $B \to l\, \nu\, \pi$'s
    but *not*

$$B \to l^- \nu\, \bar{K} K \;/\; l^- \nu\, \bar{K} K \pi$$

Real $|V_{ub}|_{incl.}$ might be smaller than thought before
  -- challenge for `duality' close to thresholds



at least novel lessons of non-perturb. QCD

(IV) Broken U- & V-spin symmetries

Forgive me to go back again about `our' history, namely

$SU(3)_{flavor}$ [not $SU(3)_{color}$] in the world of quarks:

-- `constituent' quarks: $m_u \sim 0.33$ GeV $\sim m_d$, $m_s \sim 0.5$ GeV.
It was pointed out by Lipkin that the broken $SU(3)_{flavor}$ can be described by 3 SU(2) with I-, U- & V-spin symmetries

-- (u,d) are obviously combined for I-spin

-- broken U-spin symmetry *without* V-spin is usable for *spectroscopy*, where (s,d) are combined.

-- weak decays?

- $A_{CP}(B^0 \to K^+\pi^-) = -0.082 \pm 0.006$

  [$\tau(B^0) = 1.52 \times 10^{-12}$ s, $BR(B^0 \to K^+\pi^-) = (1.96 \pm 0.05) \times 10^{-5}$]

  our early prediction (1987): $A_{CP}(B^0 \to K^+\pi^-) \sim -0.1$

  it shows the impact of Penguin diagrams,
  but semi-quantitatively ??

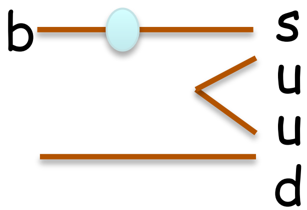
- $A_{CP}(B_s^0 \to \pi^+K^-) = +0.26 \pm 0.04$

  [$\tau(B_s^0) = 1.51 \times 10^{-12}$ s, $BR(B_s^0 \to \pi^+K^-) = (5.6 \pm 0.6) \times 10^{-6}$]

- Can we predict the connection?

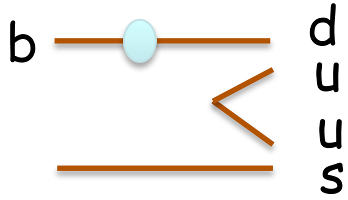
-- it had been suggested by Lipkin in 2005 to use $\boxed{\textit{U-spin sym.}}$

$B^0 \to K^+\pi^-$



$B_s^0 \to \pi^- K^+$

$d \leftrightarrow s$



$$\Delta = A_{CP}(B_d \to K^+\pi^-)/A_{CP}(B_s \to K^+\pi^-) + \Gamma(B_s \to K^-\pi^+)/\Gamma(B_d \to K^+\pi^-) = 0$$

- to get opposite signs in the SM is obvious

LHCb Collab. PRL 110 (2013) 221601:

$A_{CP}(B_s \to K^-\pi^+) = 0.27 \pm 0.04 \pm 0.01$, $A_{CP}(B_d \to K^+\pi^-) = -0.080 \pm 0.007 \pm 0.03$

$$\Delta_{LHCb} = \boxed{-0.02} \pm 0.05 \pm 0.04$$

"These results allow a *stringent* test of the validity of the …"

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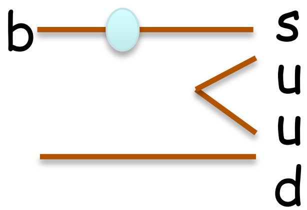

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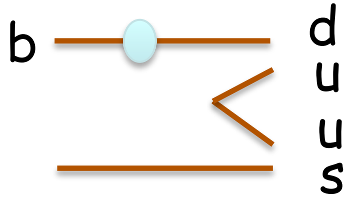

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$$\Delta_{LHCb} = -\,0.02\ \boxed{\pm\, 0.05 \pm 0.04}$$

"These results allow a *stringent* test of the validity of the …"

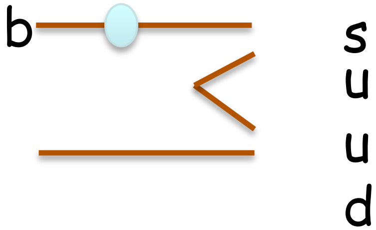
I disagree for several reasons ! Examples on the simple levels

-- Δ_{LHCb} is consistent with zero

-- Δ_{LHCb} is consistent with ~ 0.1 as expected for direct CPV for 2-body FS

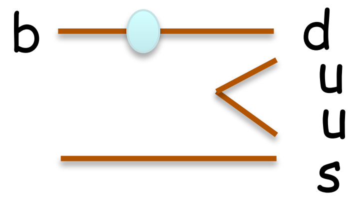
-- $\boxed{\text{correlations of U-spin with V-spin due to re-scattering}}$

$B^0 \to K^+\pi^-$



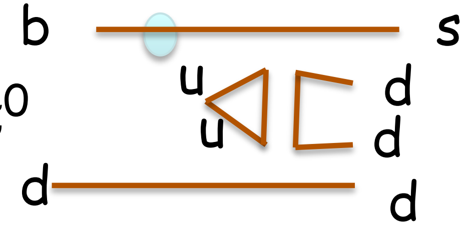
d $\longleftrightarrow$ s

$B_s^0 \to \pi^- K^+$

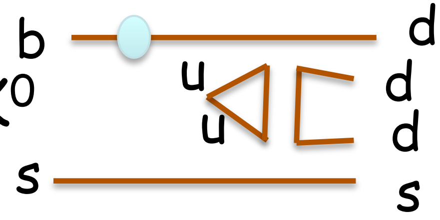


- U-spin is sizable broken
- correlations of U-spin with V-spin due to re-scattering

$B^0 \to K^0\pi^0$

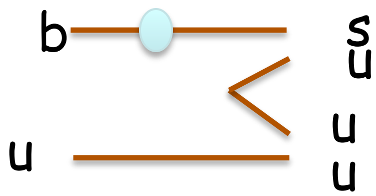


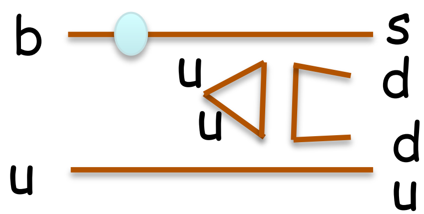
$B_s^0 \to \pi^0 K^0/\eta K^0$



$C\,(B \to K^0\pi^0) = -\,0.00 \pm 0.13$, $S\,(B^0 \to K^0\pi^0) = +\,0.58 \pm 0.17$

$B^+ \to K\pi/K^+\eta/K^+\eta$





$A_{CP}(B^+ \to K_S\pi^+) = -\,0.017 \pm 0.016$, $A_{CP}(B^+ \to K^+\pi^0) = +\,0.037 \pm 0.021$

$\boxed{A_{CP}(B^+ \to K^+\eta) = -\,0.37 \pm 0.08}$, $A_{CP}(B^+ \to K^+\eta') = +\,0.004 \pm 0.011$

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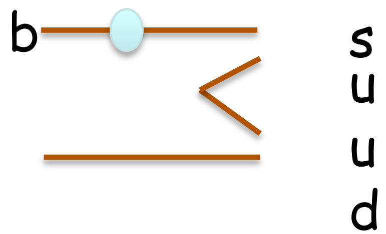

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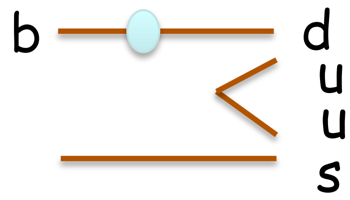

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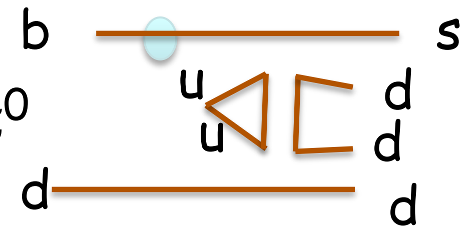

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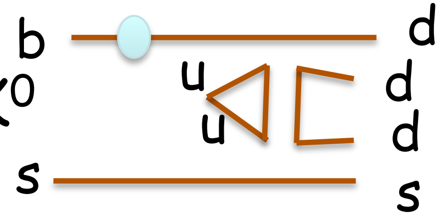

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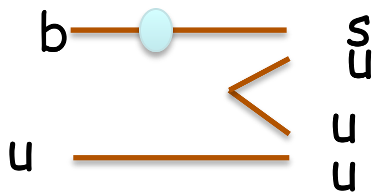

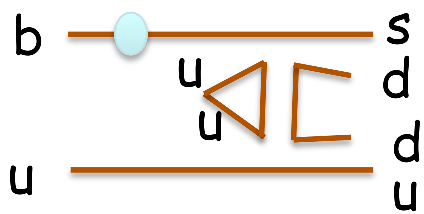

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1st lesson:difference between U- & V-spin is `fuzzy'
2nd lesson: we have to go beyond 2-body FS

(V) 3- & 4-body Final States in Beauty & Charm Mesons

-- For experimenters it is easier to measure 2-body FS (including narrow resonances) -- if one has enough data for suppressed transitions -- and for theorists to predict those & analyze the data.

-- 2-body FS of suppressed non-leptonic weak decays are a small part of charm mesons & tiny ones for beauty mesons;

- data show that;
- it is not surprising.

-- However, the final goal is to probe CP asymmetries (& very rare decays): it gives only numbers.

-- 3- & 4-body FS are described by two-& more dimensional plots.

☹ Price: lots of work both for experimenters & theorists

☺ Prize: find existence & *features* of New Dynamics (ND)!

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-- the situations are very different for $\Delta S = 1$ & 2

[listen to my Danish colleague Buras (member of the Bavarian Academy !)

- *local operators*
- FS with only one & two pions

$$T(P \to a) = \exp(i\delta_a)\,[T_a + \sum_{aj \neq a} T_{aj}\; i\; \boxed{T_{aj,a}^{resc}}\,]$$

$$T(\bar{P} \to \bar{a}) = \exp(i\delta_a)\,[T^*_a + \sum_{aj \neq a} T^*_{aj}\; i\; \boxed{T_{aj,a}^{resc}}\,]$$

$$\Delta\gamma(a) = |T(\bar{P} \to \bar{a})|^2 - |T(P \to a)|^2 = 4 \sum_{aj \neq a} \boxed{T_{aj,a}^{resc}}\; \boxed{\mathrm{Im}\, T^*_a T_{aj}}$$

With*out* strong re-scattering *direct* CP asymmetries can*not* happen, even if there are weak phases.

Misha & Misha & collab.; Wolfenstein

$$T(P \to a) = \exp(i\delta_a)\,[T_a + \sum_{aj\neq a} T_{aj}\; i\; \boxed{T_{aj,a}^{resc}}\,]$$

$$T(\bar{P} \to \bar{a}) = \exp(i\delta_a)\,[T^*_a + \sum_{aj\neq a} T^*_{aj}\; i\; \boxed{T_{aj,a}^{resc}}\,]$$

$$\Delta\gamma(a) = |T(\bar{P} \to \bar{a})|^2 - |T(P \to a)|^2 = 4\sum_{aj\neq a} \boxed{T_{aj,a}^{resc}}\; \boxed{\mathrm{Im}\, T^*_a T_{aj}}$$

With*out* strong re-scattering *direct* CP asymmetries can*not* happen, even if there are weak phases.

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The goal is: measuring CP asymmetries probes existence & even features of New Dynamics (ND), since they can depend only an amplitude.

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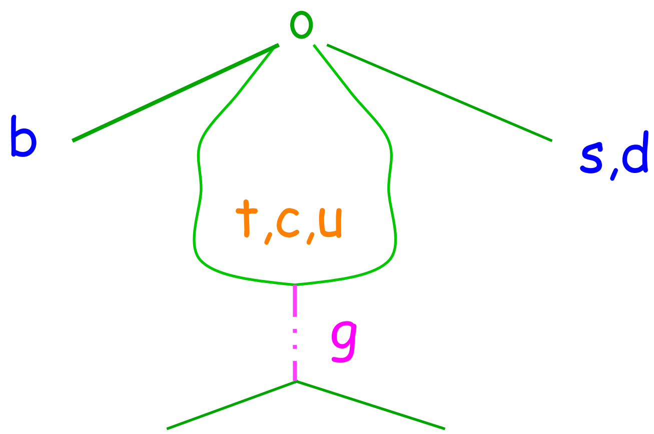
-- These statements are correct in general. However, what one means in the world of hadrons vs. world of quarks & gluons?

- One starts with one hadron & measures the hadrons in the FS.
- Mostly in the theoretical world one talks about re-scattering with quark amplitudes in between (& sometimes chiral symm.)

`penguin' diagrams



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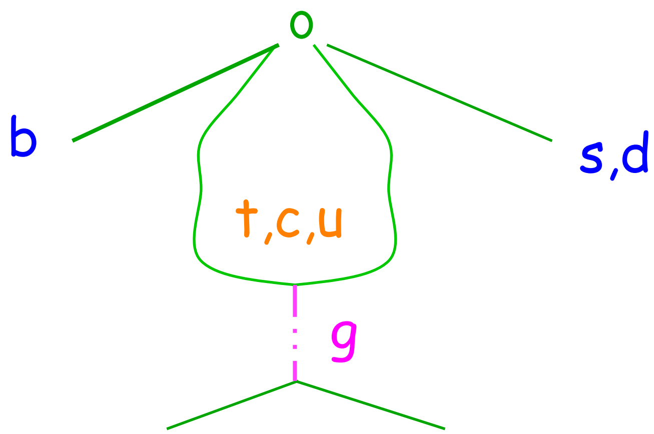
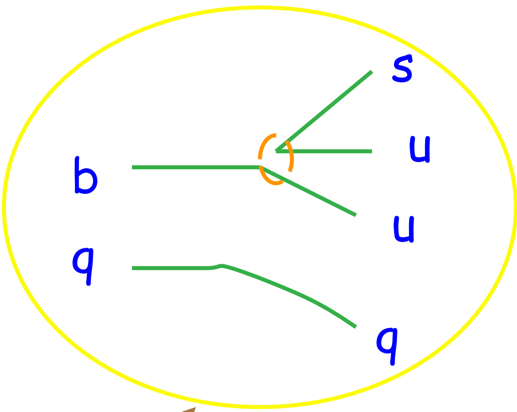
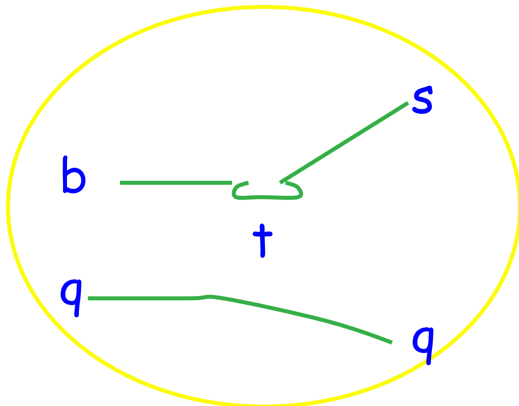


One should not only look on diagrams



local operator
with weak phase



local operator not
needed, but it is there

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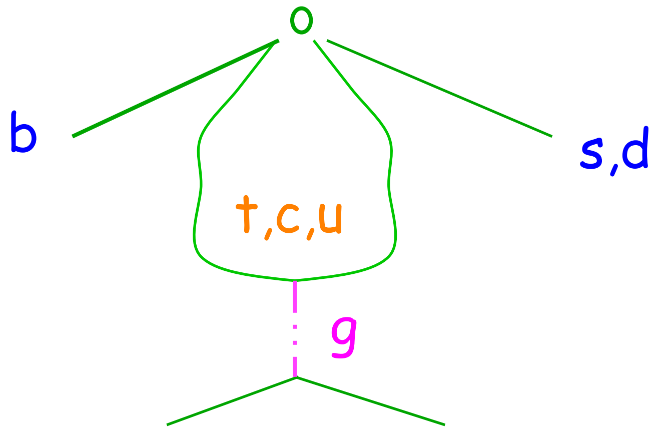

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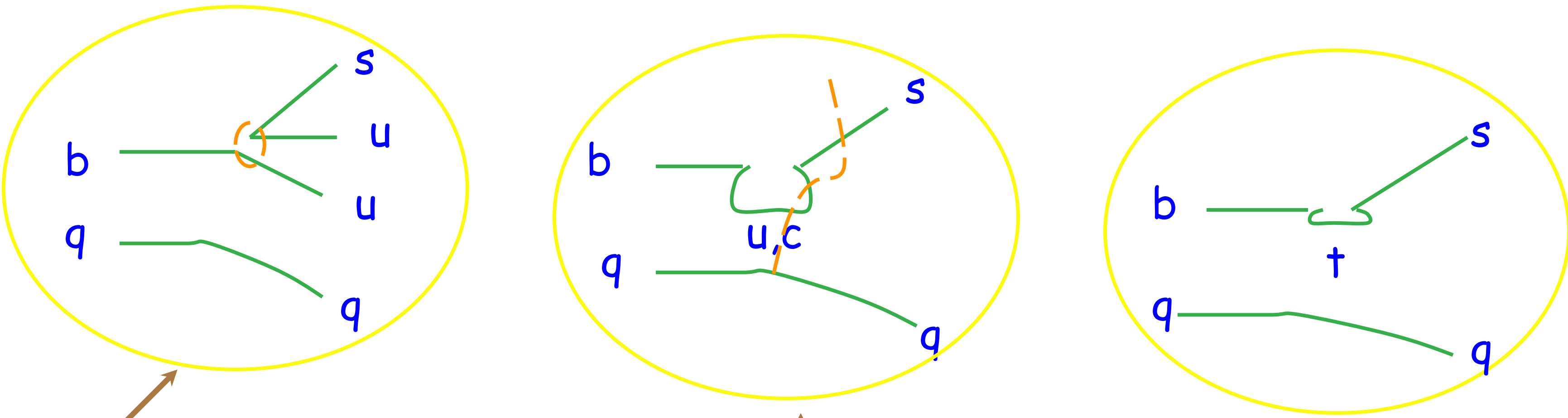


local operator with weak phase

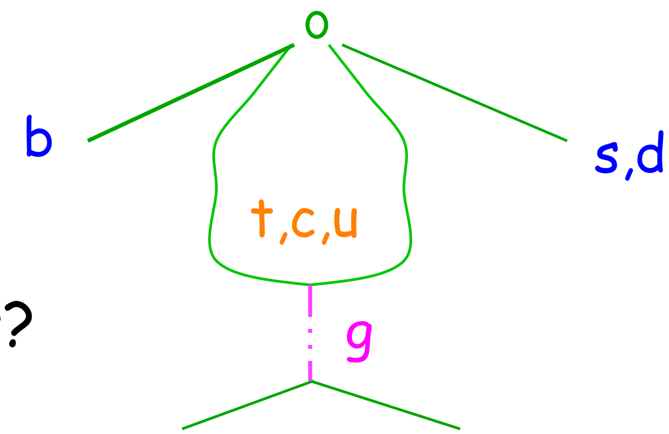
nonlocal operator with strong phase

local operator not needed, but it is there

$b \to s\,\bar{c}\,c$ & $s\,\bar{u}\,u$ `paint' re-scattering

$\Delta\gamma(a)=|T(\bar{P} \to \bar{a})|^2-|T(P \to a)|^2=4\sum_{aj\neq a} \boxed{T_{aj,a}^{resc}}\ \boxed{\mathrm{Im}\, T^*_{a} T_{aj}}$

`penguin' diagrams: well-known for inclusive one -- about *exclusive* ones?



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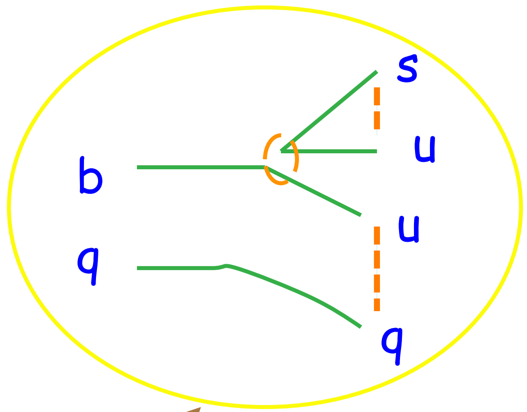

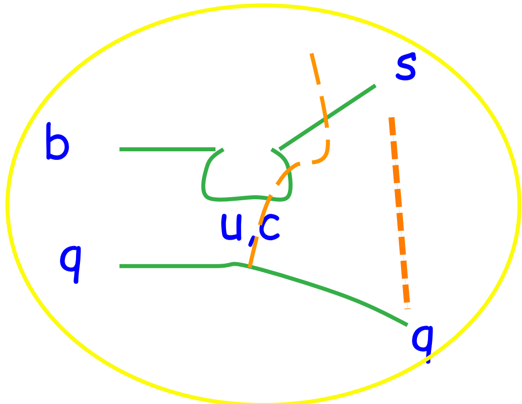

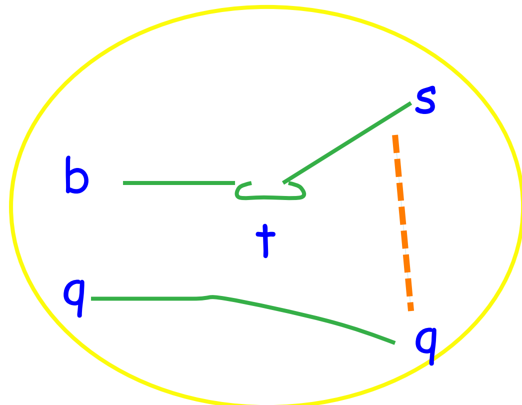

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(V.1) 3-body Final States in general

Dalitz plots (with pions, kaons, η & η') are excellent tools to probe the underlying dynamics with two observables: with*out* angular correlations a plot is flat, while resonances & thresholds show their impact from their deviations.

It has a very good record both about strong forces & weak ones.

(V.1) 3-body Final States in general

Dalitz plots (with pions, kaons, η & η') are excellent tools to probe the underlying dynamics with two observables: with*out* angular correlations a plot is flat, while resonances & thresholds show their impact from their deviations.

It has an excellent record both about strong forces & weak ones.

Four main statements:

(a) The FS are *not* described only by a sum of (semi-2-)body FS & their interferences; true 3-body FS happen in the weak decays of charm & beauty mesons.

(b) Best fitted analyses often do *not* give us the best information about the underlying dynamics.

(c) We have *broad* resonances in the region of ~ 1 – 3 GeV. Furthermore scalar ones like *sigma/*f_0*(500), kappa* etc. should *not* been described with Breit-Wigner parameterization.

(d) Maybe the centers of the Dalitz plots are far from empty?

correlations & judgments !

Not trivial to connect the world of hadrons with the diagrams of quarks & gluons. Re-scattering / non-perturbative forces !

(V.2) $B^{+/-} \to K^{+/-}\pi^+\pi^-$ vs. $B^{+/-} \to K^{+/-}K^+K^-$

LHCb data run-1 about rates:

$BR(B^+ \to K^+\pi^+\pi^-) = (5.10 \pm 0.29) \times 10^{-5}$;

$BR(B^+ \to K^+K^+K^-) = (3.37 \pm 0.22) \times 10^{-5}$;

not surprising at all

averaged CP asymmetries

$\Delta A_{CP}(B^+ \to K^+\pi^+\pi^-) = +\,0.032 \pm 0.008 \pm 0.004 \pm 0.007$;

$\Delta A_{CP}(B^+ \to K^+K^+K^-) = -\,0.043 \pm 0.009 \pm 0.003 \pm 0.007$;

it is okay

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regional CP asymmetries

$\Delta A_{CP}(B^+ \to K^+\pi^+\pi^-)|_{regional} = + 0.678 \pm 0.078 \pm 0.032 \pm 0.007$;

$\Delta A_{CP}(B^+ \to K^+K^+K^-)|_{regional} = - 0.226 \pm 0.020 \pm 0.004 \pm 0.007$;

Very surprising for me due to two connected points:

-- the centers of the Dalitz plots are mostly empty

-- the differences are so huge!

(V.3) $B^{+/-} \to \pi^{+/-}\pi^+\pi^-$ vs. $B^{+/-} \to \pi^{+/-}K^+K^-$

LHCb data run-1 about rates:

$BR(B^+ \to \pi^+\pi^+\pi^-) = (1.52 \pm 0.14) \times 10^{-5}$;

$BR(B^+ \to \pi^+K^+K^-) = (0.50 \pm 0.07) \times 10^{-5}$;

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$\Delta A_{CP}(B^+ \to \pi^+\pi^+\pi^-)|_{regional} = +\,0.584 \pm 0.082 \pm 0.027 \pm 0.007$;

$\Delta A_{CP}(B^+ \to \pi^+K^+K^-)\,|_{regional} = -\,0.648 \pm 0.070 \pm 0.013 \pm 0.007$;

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-- production $\mathcal{O}(m_b)$ vs. weak decays $\mathcal{O}(1\ \text{GeV})$!

Λ_{QCD} 0.1 – 0.3 GeV ? Look also at LQCD: $\Lambda \sim 0.7$ GeV

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underlying dynamics can be not obvious

(V.4) $\Delta\, C \neq 0$ with 4-body FS

Remember the history: $A_{CPV}(K_L \to \pi^+\pi^- e^+e^-) = (13.7 +/- 1.5)\%$
so far, no CP asymmetries has been established in charm mesons
-- SCS decays: $D^0 \to 2\pi^+2\pi^- / K^+K^-\pi^+\pi^-$:

- Averaged CPV:
  SM ~ 0.001
- Regional CPV:
  large impact of re-scattering like ~ 0.01 or more
  like for decays of $B^+ \to$ light mesons, namely factor of 10

-- DCS decays: : $D^0 \to K^+\pi^-\pi^+\pi^- / 2K^+K^-\pi^-$:

- Averaged CPV:
  basically zero for the SM
- Regional CPV:
  hunting region for ND with no SM background
  if one has large data;

at least novel lessons about non-perturbative QCD

(V.5) Future Lessons about Δ B $\neq$ 0 with Dalitz plots

-- New information about Dalitz plots from run-2&-3 about
   $B^{+/-} \to K^{+/-}\pi^+\pi^-$ vs. $B^{+/-} \to K^{+/-}K^+K^-$ and
   $B^{+/-} \to \pi^{+/-}\pi^+\pi^-$ vs. $B^{+/-} \to \pi^{+/-}K^+K^-$?
   Tools:
   - CPT invariance
   - Final steps need `judgment' about applying resonances, threshold enhancements etc with dispersion relations
     - 1st step: models;
     - 2nd step: model-independent

(V.5) Future Lessons about $\Delta B \neq 0$ with Dalitz plots

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Tools:
- CPT invariance
- Final steps need `judgment' about applying resonances, threshold enhancements etc with dispersion relations
  - 1st step: models;
  - 2nd step: model-independent
  - 3rd step: best fitted analyses often do *not* give us the best information about the underlying dynamics –

    ! *correlations* & judgments !

    We need & able to use refined theor. tools like dispersion relations; show the impact based on data at
  - low energies!

- Alliances !

(VI) Challenges for Beauty & Charm Baryons

(VI.1) CP asymmetries in the decays of Λ_b^0

-- First step: probe $\Lambda_b^0 \to p\,\pi^-/p\,K^-$;
no sign, but it is beyond realistic scale

-- I had suggested before to probe Dalitz plots
$\Lambda_b^0 \to \Lambda\pi^+\pi^-/\Lambda K^+K^-$

-- LHCb came by with a novel idea: probe $\Lambda_b^0 \to p\,\pi^-\pi^+\pi^-$
between two planes

- Its result: CPV with 3.3 σ uncertainties with
- *regional* asymmetries ~ 20 % due to $[p\,\pi^-_{fast}][\pi^+\pi^-_{slow}]$!
not surprising: $\Delta(1232)$ [$\Delta(1600)$, $\Delta(1620)$] => $p\pi^-$!

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- *Present* data & analyses about $[p\,\pi^-_{slow}][\pi^+\pi^-_{fast}]$?
  No predictions – we have to learn from the (re-fined) data !
  Vincenzo told me at CERN last Fall: they can do it quickly.

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-- probe $\Lambda_b^0 \to p\,\pi^-K^+K^-$ where 3 mesons are different

-- likewise $\Lambda_b^0 \to p\,K^-\pi^+\pi^-$[different]/$pK^-K^+K^-$ [complex]

-- application of QFT are subtle due to non-local interferences

-- thus decays of Λ_b^0 are excellent cases of underlying dynamics

(VI.2) Present and future lessons $\Delta C \neq 0$

-- When one goes for CPV, one can*not* stop at 2-body FS. It is crucial to probe 3- & 4-body FS including regional CPV.

-- On first & second steps one goes after SCS ones where the SM predicts small CPV on the order of $\mathcal{O}(10^{-3})$.

-- For DCS decays the SM predicts basically zero; hunting regions for ND.

-- One has to probe CPV in charm baryons with Dalitz plots

- SCS: $\Lambda^+_c \to p\, \pi^+\pi^- \,/\, p\, K^+K^-$
- DCS: $\Lambda^+_c \to p\, K^+\pi^-$

(VII)The Stage of top quarks: *direct* Search for New Dynamics

-- top quarks decay *before* they can produce top hadrons.
[ibi, Y. Dokshitzer, V. Khoze, J. Kuehn, P. Zerwas, PLB181(1986)157]
Yet they carry "color"; thus they can evolve with other "color" states in connection to produce hadrons with*out* "color" in the end.

-- pairs of top quarks and single ones

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-- pairs of top quarks and single ones

-- `Hot' item: $pp \to H^0 + t + \bar{t} + X$ with "color" connection X in the finished run-2 of LHC & the future run-3.

-- In the future *pp* collisions one can discuss an even more challenges: $pp \to H^0 + t + X$ vs. $pp \to H^0 + \bar{t} + X$;
maybe find the impact of ND there with *single* productions, in particular about CP asymmetries.

(VII)The Stage of top quarks: *direct* Search for New Dynamics

(VII.1) Probing CPV with*out* Higgs connection with *pair* of tops

(VII.1.1) pp collisions with a pair of $(bW-)_t \ldots (bW+)_t$

-- center region: $gg \to (bW-)_t \ldots (bW+)_t$;
-- forward(backward) region: $qg \to q\,\bar{t}\,t\,g$ with $q = u, d$;
it is very unlikely to find CP asymmetries there; on the other hand, one might learn new lessons about very heavy resonances

(VII.1.2) pp collisions with a pair of $(\bar{b}W-)_t \ldots (q'W+)_t/(\bar{q}'W-)_t \ldots (bW+)_t$, $q'= s,d$

One might find CP asymmetries there; a possible source is an asymmetric Dark Matter.

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(VII.2) Probing CPV with*out* Higgs connection with a single top

$$pp \to W^- t\, X \to W^-[bW^+]_t\, X \quad \text{vs.} \quad pp \to W^+ \bar{t}\, X \to W^+[\bar{b}W^-]_t\, X$$

to be more precise:

$$b\, g \to W^-\, t\, g \to W^-[bW^+] \quad \text{vs.} \quad \bar{b}\, g \to W^+\, \bar{t}\, g \to W^+[\bar{b}W^-]g$$

One might find CP asymmetries there; a possible source is an asymmetric Dark Matter.

(VII)The Stage of top quarks: *direct* Search for New Dynamics

(VII.3) Probing CPV *with on-*shell Higgs dynamics

Collisions at LHC have enough energies to produce very often:

$$p\, p \to H^0\, \bar{t}\, t\ \ X$$

the challenge is to find them due to huge background.

Talk about short distance forces:

$$g\, g \to \bar{t}\, H^0\, t\ ;$$

the `painting' helps to understand the underlying dynamics.

(VII)The Stage of top quarks: *direct* Search for New Dynamics

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Talk about short distance forces:

$$g\,g \to \bar{t}\,H^0\,t\,;$$

the `painting' helps to understand the underlying dynamics.
Unfortunately I did *not* attend the 10th International Workshop on Top Quark Physics in the September 2017.
I disagree with some statements made on talks there that one can find now in the arXiv & give short comments.
First I admire the courage of these experimenters that enter these challenges!

It will make progress, but it will need time to make real achievement.

(VII.4) Definition of the mass of the top quark:"$\overline{MS}$","kinetic","PS"

-- Are top quarks `free'?

- As said above local color symmetry is *un*broken; thus one can find another obvious color source.
- Pole mass is gauge independent for top quarks; furthermore, it is *perturbative* infrared in QCD. However, it is *not* infrared stable *non-perturbatively*.
- It is easy to apply pole mass in Feynman graphs. Yet pole mass depend on long distance dynamics, for what we have little control.
- Now I talk specifically about top quarks.

(VII.4) Definition of the mass of the top quark:"$\overline{\mathrm{MS}}$","kinetic","PS"

-- *claimed* that the pole mass for the top quark is very good

- It seems that experimenters are happy to hear that by comparing their results/analyses with Feynman *diagrams*.
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- However, some papers from theorists say that the connection of experiments with theories are not obviously.
  - Can*not* ignore the impact of renormalons for top quarks.
    - "kinetic" $\neq$ "PS"="potential-subtracted":

      [While we *dis*agree with Beneke in details, both are basically in the same `*game*';
      technical problem arise $O(\alpha_S{}^4)$;
      claimed systematical uncertainty ~ 0.1-0.25 GeV ?
      I am *not* convinced by this scale.]
    - Main real challenge:

      experimental analyses vs. underlying theories ??

(VIII) Needed Collaboration of HEP & MEP/Hadrodynamics

The ruler of a Greek city in southern Italy once approached the resident sage (Pythagoras) with the request to be educated in mathematics, but in a "royal way", since he was busy with many obligations.

Whereupon Pythagoras replied with admirable candor:

"There is no royal way to mathematics."

Likewise is there no "royal insights" into Nature's inner working.

(VIII) Needed Collaboration of HEP & MEP/Hadrodynamics

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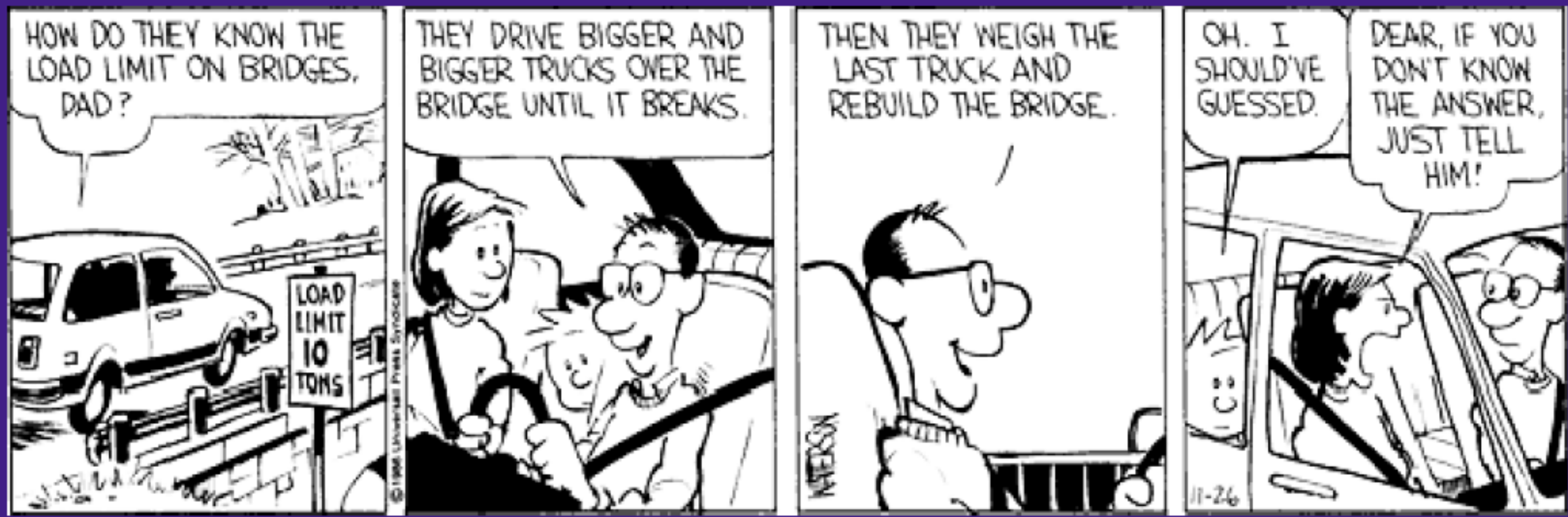
Maybe history is too subtle; this one clearer?



http://www.geocities.com/Hollywood/Theater/9876/askdad1.html

-- history

→ NP → HEP

↑

flavor dynamics

-- history

→ NP → HEP

flavor dynamics

-- now

→ NP → MEP/Hadrodynamics → HEP

decays of strange/
beauty/charm mesons & baryons
Dalitz plots
dispersion relations
accuracy/precision

jets,
Higgs, top quarks
direct SUSY

different landscapes & "cultures": it is not easy, but important

- pions, kaons, ..., N, ... vs. quarks, gluons, gauge bosons, Higgs ...
- 3- & 4-body FS and regional CP asymmetries

Final steps need `judgment' about applying resonances, threshold enhancements etc. with dispersion relations

-- 1st step: models;

-- 2nd step: model-independent

-- 3rd step: best fitted analyses often do *not* give us the best information about the underlying dynamics –

! *correlations* & judgments !

Yes, the data are the referees, but in the end - theorists should not be the slaves of the data !

`thinking is better than power'

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`dreaming in more dimensions'

Kolya Uraltsev & I had looked at this painting in person and realized that it is symbol of collaboration.

"Goals for *flavor dynamics* of quarks":

☞ `battle for supremacy' has been decided

✍ goal no longer to find alternatives to CKM –
instead to identify corrections to CKM!

☞ Baryogenesis ? No!

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➥`hypothesis-generating' rather than `hypothesis-probing'

to be honest (& biased): I see 3 candidates for ND:

-- SUSY, which is a huge class (or more)

-- axions (including parts of DM)

-- new leptonic dynamics (neutrino oscillations etc.)

- flavor lepton dynamics ?
- connection of quark & lepton dynamics ?
- Leptogenesis leading to Baryogenesis ?

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- no analogy to the well-known history (I hope)

-- Motto: *Non*-perturbative QCD & *many-body* final states.

-- The best tools are CP asymmetries, but subtle & complex.

-- The dynamics of beauty & charm hadrons & top quarks:
I follow an old Austria saying: they are the same, only differently!

-- LHCb & Belle II go for accuracy, when the SM gives *non*-zero values there; yet ATLAS/CMS go for obvious hunting region for ND.

-- Feynman *diagrams* can give the direction about ND, but *not* trust the final analyses.

-- best fitted analyses often do *not* give the best information about the dynamics – *correlations* & judgments !

-- The landscapes are obviously very different for quark & lepton dynamics.

Backup slides

"*not all* OPE's are created *equally* !"

We have better use

Wilsonian OPE !

B -> l ν X

hep-ph/0403166

Uraltsev