V2.5

"Finding New Dynamics by *Judgments*"

Motto: Impact of Non-perturbative QCD on CP Violation in Many-Body Final States of Flavor Transitions

Ikaros Islam Bigi, Notre Dame du Lac

Primosten, October 2019

When Gods speak in Riddles

? Tragic Oracles & Tragic Mis-understanding ?

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"On seeing the missile shot by a catapult which had been brought then for the first time from Sicily", the king from Sparta in the fourth century B.C. cried out:
`By Heracles, this is the end of man's valor.' "

V2.5

When Gods (Symmetries) speak in Riddles

? Tragic Oracles & Tragic Mis-understanding ?

LHCb & Belle II both as a pioneer about non-pert. QCD & weak dynamics - as a team of experimenters and HEP theorists [as before BaBar & Belle]

experimenters

theorists

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Analogy of physicists with computers?

* Manifestation of a *divine* being through something both simple & striking: local symmetries & their tools !

Fitting the data vs. *Information* inside the data

1st step: models

2nd step: model-independent analyses – indeed, true progress

3rd step: best fitted analyses often do *not* give the best information about the underlying dynamics; data are the referees – in the end !

crucial: *collaborations* of experimenters & theorists with *correlations* & judgments !

Prof. Mannelli from Pisa once assured me that he does *not* entertain the illusion that theorists can speak the truth all the time -- speaking in good faith is all he expects from theorists !

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My *goals* for this WS:

establish the existence of ND (New Dynamics) & their features

Tools:

-- probe *many-body* non-leptonic FS

-- collaboration of HEP & MEP/Hadrodynamics from different `cultures' !

(I) Introduct: *Wilsonian* OPE, *broken* U- & V-spin symmetries

(II) *Quark Masses* in *Quantum Field Theories* (QFT)

(III) *Consistent* Parameterization of the CKM Matrix

(IV) Intermezzo: *CP asymmetry* in $D^0 \to K^+K^-/\pi^+\pi^-$

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

(VI) Challenges for Beauty & Charm & Strange *Baryons*

Epilogue for the future: *Collaboration* of HEP & Hadrodynamics

(VII) Summary: Impact of *non*-perturbative QCD on *CP Violation*

The slides I think are very important see the symbol *

← I had produced this picture; later I will explain why it is *not* about bragging rights.

(I) Introduction: *Wilsonian* OPE, *broken* U- & V-spin symmetries

(I.1) *Wilsonian* Operator Product Expansion (OPE)

If QCD is solved, $L(\mu)$ could be moved down to the scale $\mu = 0$ in terms of physical hadrons rather than quarks & gluons. Their amplitudes could be described with pole masses as observables.
*That is `Utopian'!* Thus one has to use quarks & gluons going down to $\mu \sim 1$ GeV; *effective* Lagrangians are functions of $\mu$. `We' need more tools;

one is *Operator Product Expansion* !

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Almost all invoke OPE -- often *without* using *Wilsonian* prescription!

However: "*not* all OPE's are created equality"!

Shifman & collaborators had emphasized applying OPE is subtle:

the *Wilsonian* OPE *stops* at ~ 1 GeV, not sizably lower *

arXiv: hep-ph/9703290 (BSU):

effective Lagrangian $T(H \to f) = \cdots \Sigma_i\, c_i(\mu) \langle f|O_i(\mu)|H\rangle$

with "soft" < μ < "hard"; μ demarcation between long- & short-distance forces

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It is one thing to draw diagrams, while another thing is understand the underlying dynamics – like non-perturbative QCD with some accuracy.

Quote of Marinus (~468 AD student of Proklos, Neoplatonist philosopher)

"Only *being* good is one thing – but good *doing* is the other one!"

(I.2) *broken* U- & V-spin symmetries

-- *broken* global $SU(3)_{flavor}$ can be described by 3 SU(2) with I-, U- & V-spin symmetries
-- (u,d) are obviously combined for Iso-spin symmetry
-- *broken* U-spin symmetry [s,d] *without* V-spin [s,u] is okay for *strong spectroscopy*.

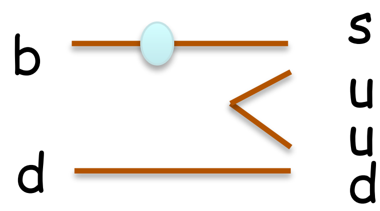
However:
-- *weak* decays?
- $A_{CP}(B^0 \to K^+\pi^-) = -0.083 \pm 0.004$
  $[\tau(B^0) \approx 1.52 \times 10^{-12}$ s, $BR(B^0 \to K^+\pi^-) = (1.96 \pm 0.05) \times 10^{-5}]$
  1987 prediction by Uraltsev, IIB, ...: $A_{CP}(B^0 \to K^+\pi^-) \sim -0.1$
  it shows the impact of Penguin diagrams, but semi-quantitatively ??

- $A_{CP}(B_s^0 \to \pi^+K^-) = +0.221 \pm 0.015$
  $[\tau(B_s^0) \approx 1.51 \times 10^{-12}$ s, $BR(B_s^0 \to \pi^+K^-) = (0.56 \pm 0.06) \times 10^{-5}]$

- Can we predict this connection with the 2018 data from run-1?

-- it had been suggested by Lipkin in 2005 to use *U-spin symmetry* ✱

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



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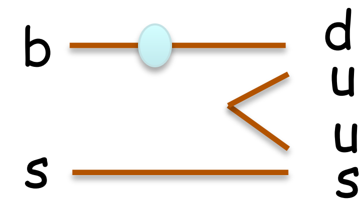

\`Popes' know \`our' world is *not* perfect; in this case of Lipkin:

$\tau(B_d) \approx \tau(B_s)$: $A_{CP}(B_d \to K^+\pi^-)/A_{CP}(B_s \to \pi^+K^-) \neq 1$, $\Gamma(B_s \to \pi^+K^-)/\Gamma(B_d \to K^+\pi^-) \neq 1$

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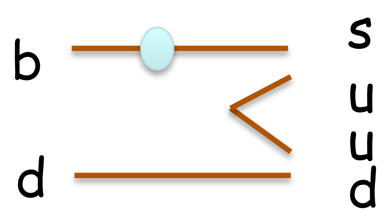

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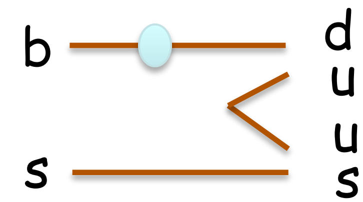

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LHCb Collab. PRL 110 (2013) 221601 $\Delta_{LHCb} = -0.02 \pm 0.05 \pm 0.04$

\`These results allow a stringent test of the validity of this relation … in the SM given' (\`Lipkin rule')

-- indeed, Δ_{LHCb} is consistent with zero

-- $|\Delta_{LHCb}|$ is consistent also with ~ 0.1 as expected for direct CPV in 2-body FS

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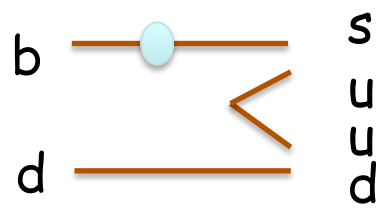

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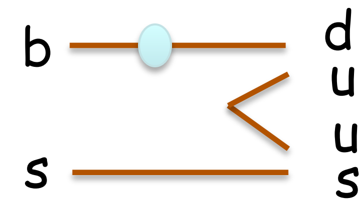
d ⟷ s



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LHCb. PRD 98 (2018) 032004 (all data from the run-1): $\Delta_{LHCb} = -\,0.11 \pm 0.04 \pm 0.03$

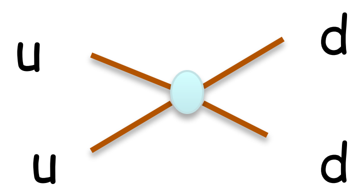
-- Δ_{LHCb} is still consistent with zero

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

-- other lessons ?

Results from run-1: Δ_{LHCb} = - 0.11 ± 0.04 ± 0.03

-- correlations of U-spin amplitudes with V-spin ones due to *re-scattering*



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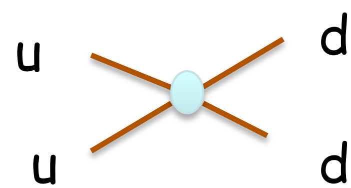

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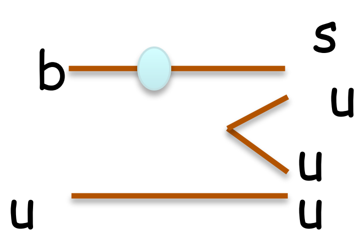
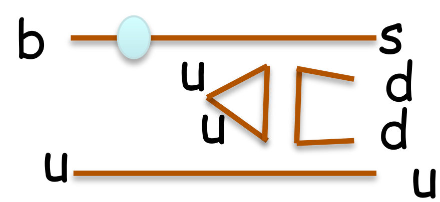
B^+ -> $K\pi/K^+\eta/K^+\eta'$





Iso-spin symmetry

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

$A_{CP}(B^+ \to \eta\, K^+)$= - 0.37±0.08 , $A_{CP}(B^+ \to \eta'\, K^+)$= +0.004±0.011, $A_{CP}(B^+ \to \rho\, K^+)$= + 0.37±0.10

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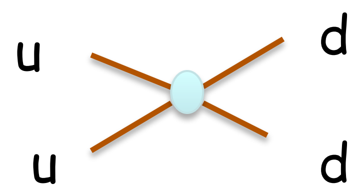

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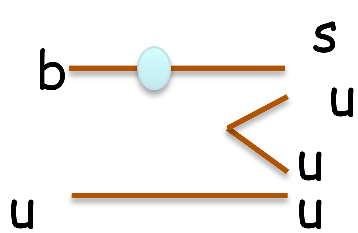

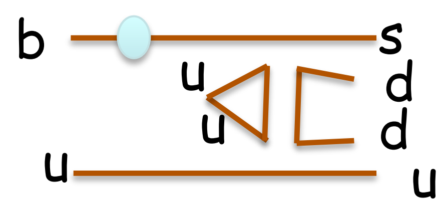

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1st lesson: difference between U- & V-spin is `fuzzy'
2nd lesson: we have to go *well beyond 2-body* FS

(II) Quark Masses in Quantum Field Theories (QFT)

(II.1) General statements

-- 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 diagrams.
Yet pole mass depend on long distance dynamics, for what we have little control.

-- One can*not* ignore the impact of *IR Renormalons*; however, I will not discuss here.
To get a deeper understanding of non-perturbative QCD, see:

M. Shifman, in "QCD & Heavy Quarks, In Memoriam Nikolai Uraltsev", World Scientific; arXiv:1310.1966 [hep-th]

(II.2) Definitions of Quark Masses:"MS","kinetic", "PS"; `1S',`pole mass'

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

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The `landscape' is very different from the *weak decays* of H_Q.

-- The "kinetic scheme" regular in the IR region is the best
$dm^{kin}_Q(\mu)/d\mu = -(16\alpha_S/9\pi) - (4\alpha_S/3\pi)(\mu/m_Q) + \mathcal{O}(\alpha_S^2)$

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-- PDG2018 review basically ignores "kinetic" & "PS" schemes, while focus in the `1S scheme' with $m_b^{1S} \approx M_{\Upsilon(1S)}/2$

It claims these schemes give us the same information about underlying dynamics -- however, I quite disagree !

Uraltsev pointed out: $m_b^{1S} = m_b^{pole}[1 - C_F^2(\alpha_S^2/\pi) +/- \mathcal{O}(\alpha_S^3, \beta_0\alpha_S^3 \log \alpha_S)]$;
$m_b^{1S} \approx M_{\Upsilon(1S)}/2$ is a `easy scheme',

yet it is *not* well-defined at the *non-perturb.* level !

(III) Parameterization of the CKM Matrix

(III.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 $\lambda = 0.223$, while A, ρ, η are $\mathcal{O}(1)$.

In the `real' world:
measured values give
$A \approx 0.82$ -- but $\eta \approx 0.35$, $\rho \approx 0.14$ not close to unity;
-- thus not real control over *systematic* uncertainties.

(III.2) *Consistent* parameterization

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

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

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

Pattern is not so obvious as before: *

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

- *hunting region for ND*!

-- ...

(IV) Intermezzo – *Direct CP asymmetry* in D^0 -> K+K- vs. π+π- !

Now we are just entering a new era:

for the first time CP violation has been established in $\Delta C \neq 0$!

LHCb collaboration has shown its data from the run-1 & run-2:

! $\Delta A_{CP} = A_{CP}(D^0 \to K^+K^-) - A_{CP}(D^0 \to \pi^+\pi^-) = (-15.4 \pm 2.9) \times 10^{-4}$!

indirect CPV was found first in $\Delta S \neq 0 \neq \Delta B$, but not yet for $\Delta C \neq 0$;
SM `paints' the `landscape' for indirect CPV ~ $10^{-4} - 10^{-3}$.
Here I talk about SCS rates [below I will discuss DCS ones]:

-- BR(D^0 -> K+K-) ~ 4×10^{-3} vs. BR(D^0 -> π+π-) ~ 1.4×10^{-3};
-- BR(D^+ -> K+K_S) ~ 2.8×10^{-3} ;
-- BR(D_s^+ -> π+K_S) ~ 1.2×10^{-3} ;

three comments:
-- first one probes direct CP asymmetries in 2-body FS;
-- present data show the impact of FSI ?
-- it is crucial to probe 3- & 4-body FS; I will come back below.

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

(1) For experimenters it is easier to measure 2-body FS
(& narrow resonances) for suppressed transitions;
for theorists to predict those & to analyze the data.

(2) However, the goal is to probe CPV: it gives only numbers.

(3) 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.

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

☹ Price: lots of data & work both for experimenters & theorists

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

-- the situations are very different for $\Delta S = 1$ & 2
- local operators
- FS with only one & two pions

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

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

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

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

Misha & Misha & collab.; Wolfenstein

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

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

There are tools to deal with much more & `complex' data:

- -- fitting the data is the 2nd step, but not the final one!
- -- unitary
- -- dispersion relations …
- -- chiral symmetry: pions [+++], kaons [++/+] ?

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

*

Dalitz plots (with pions, kaons, η & η') probe the underlying dynamics with two observables: with*out* angular correlations a plot is flat, while resonances & thresholds show their impact from their deviations; excellent record both about strong forces & weak ones.

Three main statements:

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

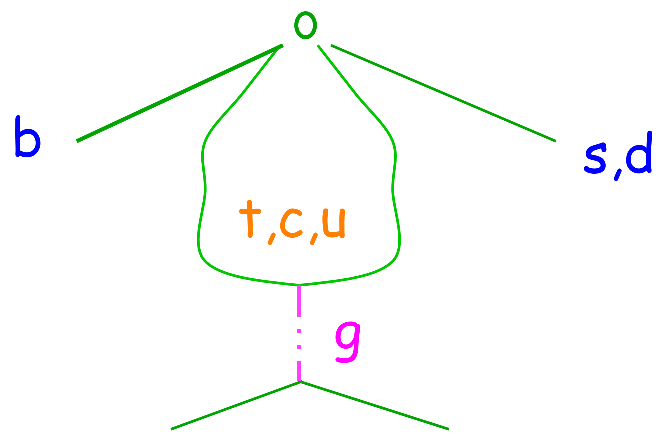
(b) We have *broad* resonances in the region of ~ 1 – 3 GeV; scalar ones like $f_0(500)$/ *sigma*, $K^*_0(700)$/*kappa* etc. can*not* been described with Breit-Wigner parameterization.

(c) Maybe the centers of the Dalitz plots are somewhat empty?

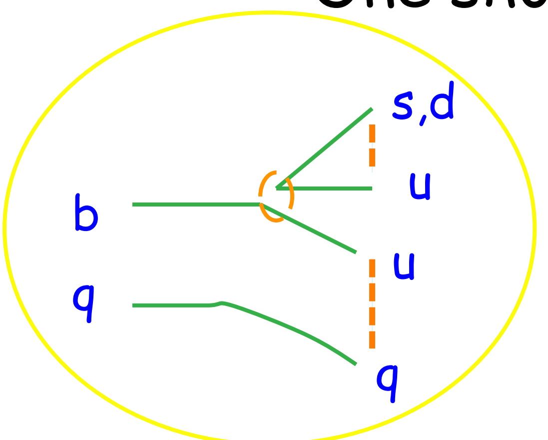
correlations & judgments !

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

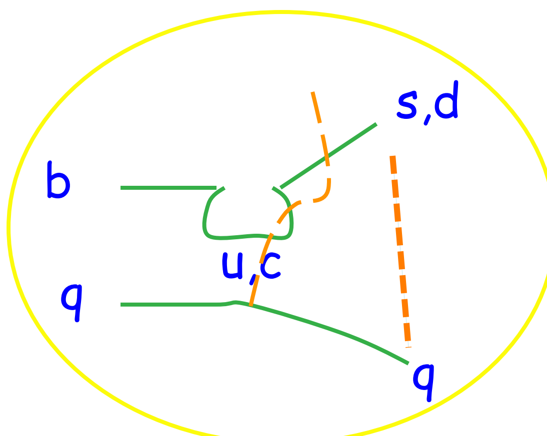
`penguin' diagrams:
well-known for
inclusive one --



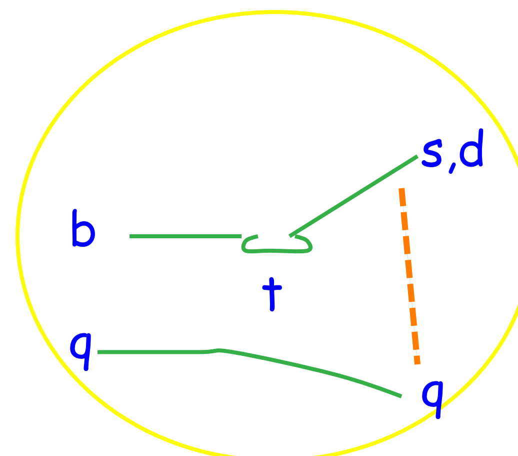
One should *not only* look on diagrams



local operator
with weak phase



nonlocal operator
with strong phase



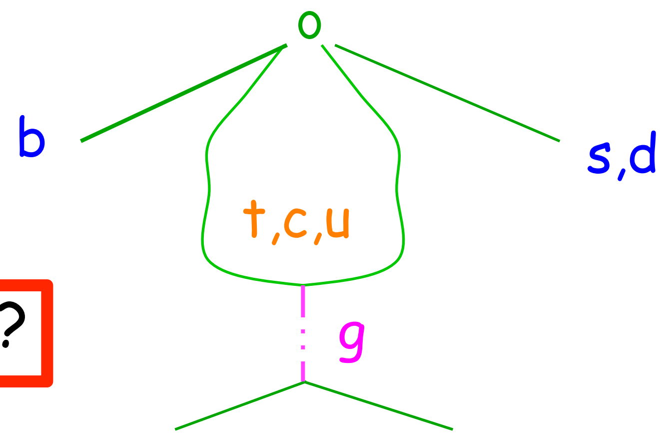
local operator not
needed, but it is there

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

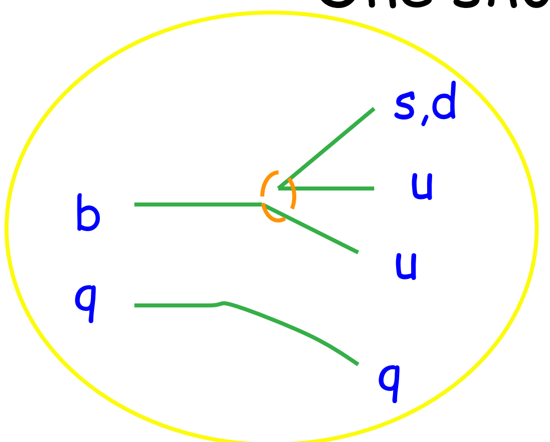
$\Delta\gamma(a)=|T(\bar{P} \to \bar{a})|^2-|T(P \to a)|^2=4\sum_{aj\neq a} T_{aj,a}^{resc}\ \mathrm{Im}\, T^*_a T_{aj}$

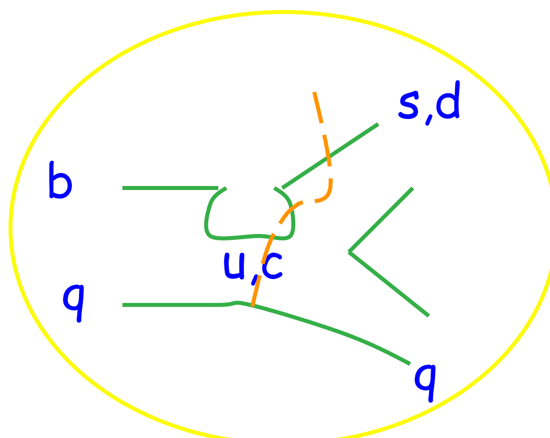
IIBigiV25

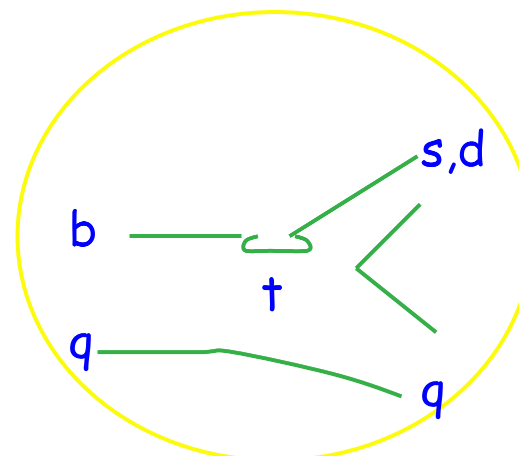
`penguin' diagrams:
well-known for
inclusive one --
about *exclusive* ones?



One should *not only* look on diagrams







local operator
with weak phase

nonlocal operator
with strong phase

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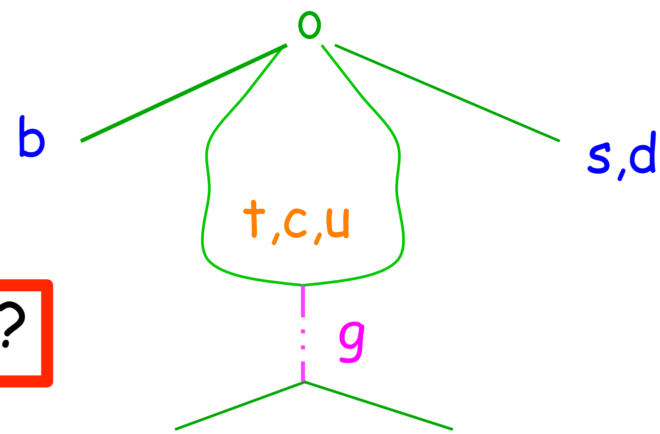
$$\Delta\gamma(a)=|T(\bar{P} \to \bar{a})|^2-|T(P \to a)|^2=4\sum_{aj\neq a} T_{aj,a}^{resc}\ \mathrm{Im}\, T^*_a T_{aj}$$

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



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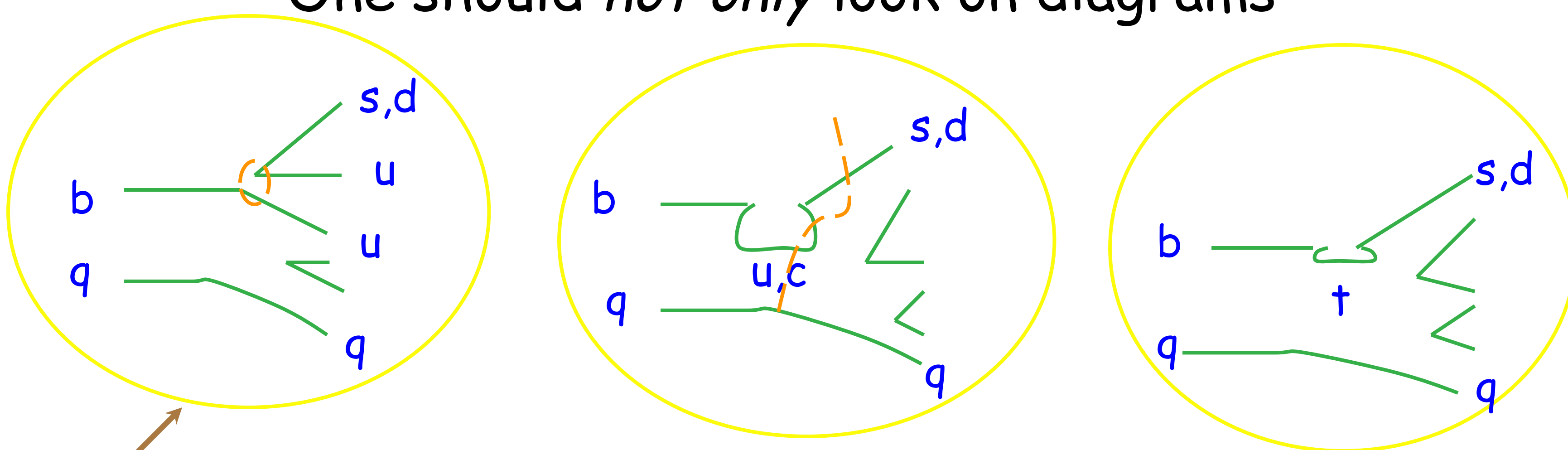


local operator with weak phase

nonlocal operator with strong phase

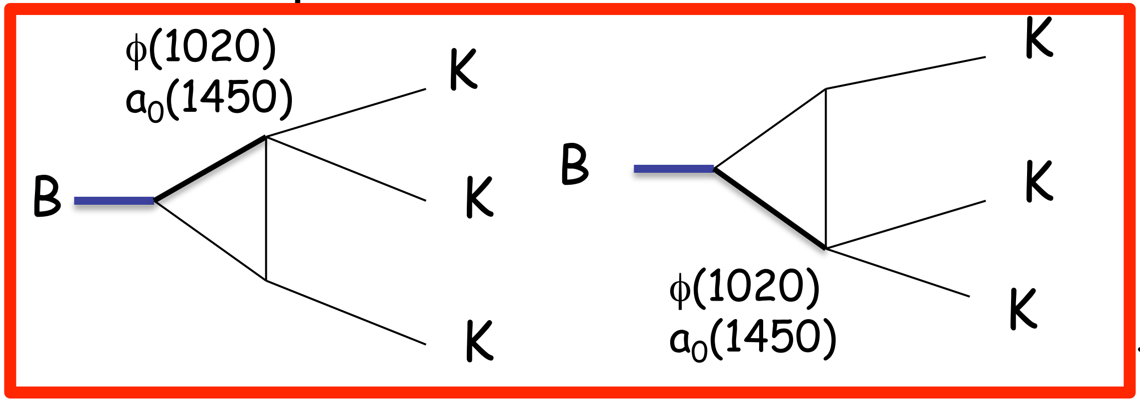
local operator not needed, but it is there

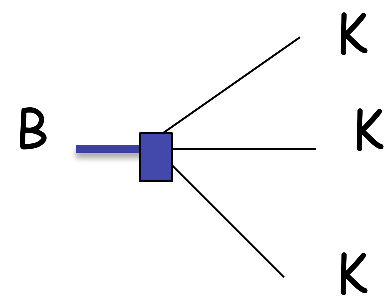
$b \to s\,\bar{c}\,c$ & $s\,\bar{u}\,u$ `paint' re-scattering

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

IIBigiV25

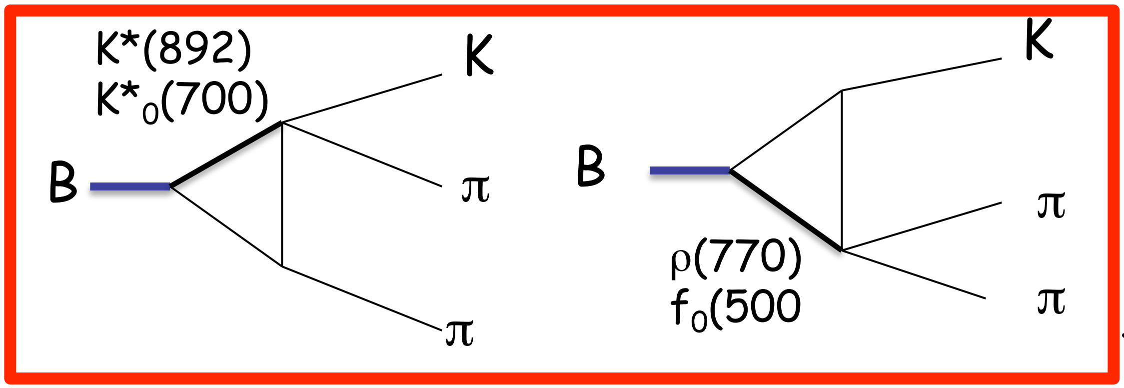
The landscapes of hadrons

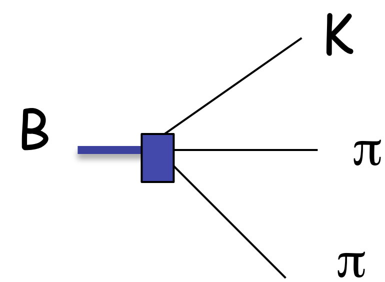




`effective'(=non-local) operators

Re-scattering is crucial to understand the underlying dynamics !





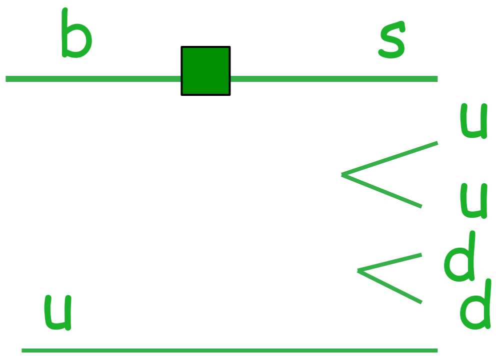
`effective'(=non-local) operators

One needs `judgment' about applying *resonances*, *threshold enhancements* etc. with tools like *dispersion relations*

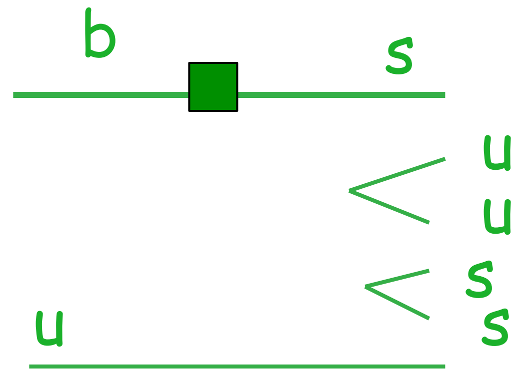
[LHCb for *DCS* decays,arXiv:1902.05884v3[hep-ex] about 8 TeV
`Dalitz plot analysis of the D+ -> K-K+K+ decay' with the Figure 9(a) on p. 12 only the top diagram, but *not* the bottom one; I disagree which I will explain below.]

Look at quark diagrams:

b -> s -- impact of Penguin diagrams in the SM

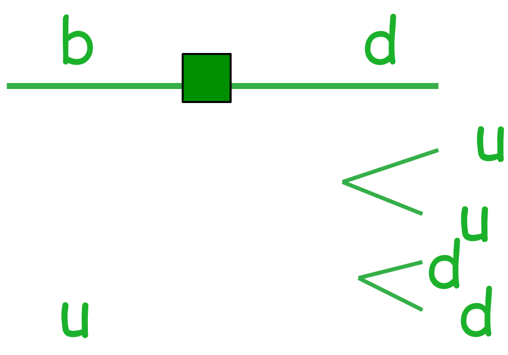


B+ -> $K^+\pi^+\pi^-$

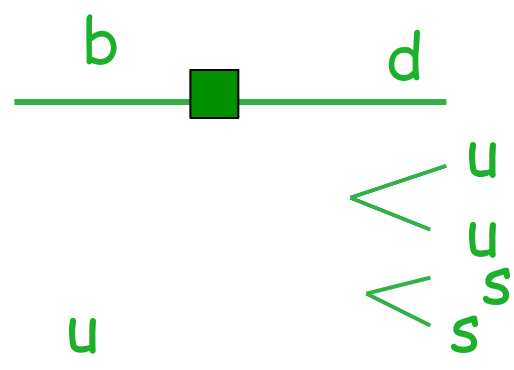


B+ -> $K^+K^+K^-$

b -> d -- less impact of Penguin diagrams in the SM

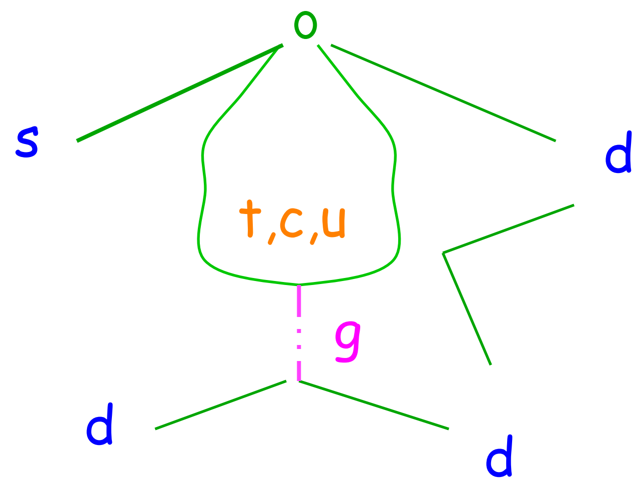


B+ -> $\pi^+\pi^+\pi^-$

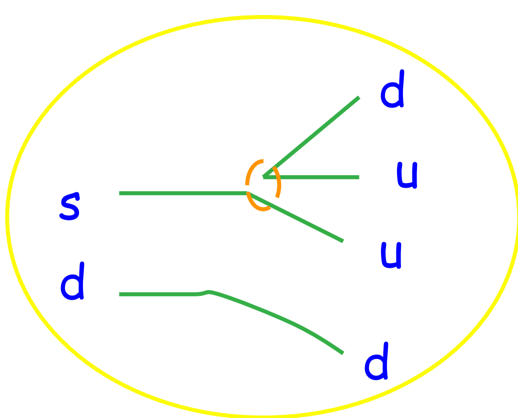


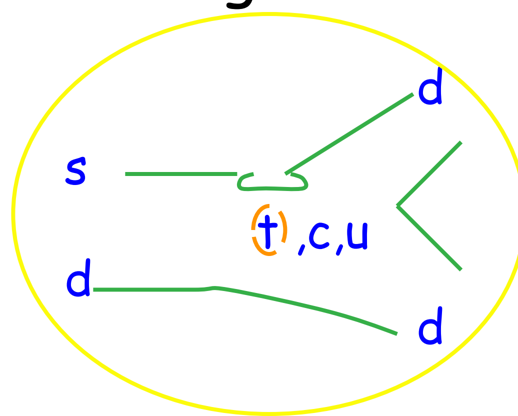
B+ -> $\pi^+K^+K^-$

History:
\`penguin' diagrams



One should *not only* look on diagrams





local operator

*

local penguin *operator* for $K^0 \to 2\pi$
-- with weak phase

(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

$\Delta A_{CP}(B^+ \to K^+\pi^+\pi^-) = + 0.025 \pm 0.004 \pm 0.004 \pm 0.007$; [LHCb Jan. 2019]

$\Delta A_{CP}(B^+ \to K^+K^+K^-) = - 0.036 \pm 0.004 \pm 0.003 \pm 0.007$; [LHCb Jan. 2019]

it is okay

`*regional*' CP asymmetries

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

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

Very surprising due to two connected points:

-- the centers of the Dalitz plots are somewhat 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:

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

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

not surprising

averaged CP asymmetries

$\Delta A_{CP}(B^+ \to \pi^+\pi^+\pi^-) = +0.058 \pm 0.008 \pm 0.009 \pm 0.007$; [LHCb Jan. 2019]

$\Delta A_{CP}(B^+ \to \pi^+K^+K^-) = -0.123 \pm 0.017 \pm 0.012 \pm 0.007$; [LHCb Jan. 2019]

maybe surprising

`regional' CP asymmetries *

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

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

Very surprising due to two connected points:

-- the centers of the Dalitz plots are somewhat empty

-- the differences are so huge!

underlying dynamics are not obvious

(V.4) CP asymmetries with $\Delta C \neq 0$

April 2019: LHCb Collaboration has established *direct* CP asymmetry

Next steps:
-- Indirect CP violation

-- *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

-- *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) $\Delta C \neq 0$ with 3-body FS

PDG2018 for *DCS* decays:

BR(D+ -> K+K+K-)/BR(D+ -> K-π+π+) = $(0.95 \pm 0.22) \times 10^{-3}$
BR(D+ -> K+π+π-)/BR(D+ -> K-π+π+) = $(5.77 \pm 0.22) \times 10^{-3}$
BR(D_s^+ -> K+π-K+)/BR(D_s^+ ->K-K+π+) = $(2.33 \pm 0.23) \times 10^{-3}$

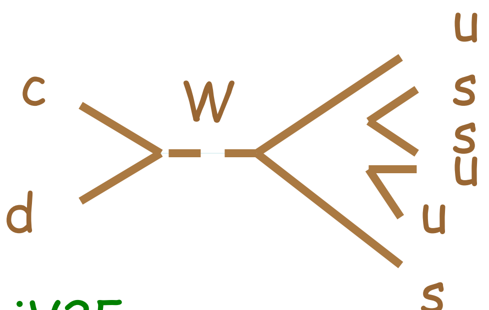
LHCb for *DCS* decays, arXiv:1810.03138 [hep-ex] about 8 TeV (not run-2)
published in JHEP 03 (2019) 176

BR(D+ -> K+K+K-)/BR(D+ -> K-π+π+) = $(0.6541 \pm 0.0025 \pm 0.0042) \times 10^{-3}$
BR(D+ -> K+π+π-)/BR(D+ -> K-π+π+) = $(5.231 \pm 0.009 \pm 0.023) \times 10^{-3}$
BR(D_s^+ -> K+π-K+)/BR(D_s^+ ->K-K+π+) = $(2.372 \pm 0.024 \pm 0.025) \times 10^{-3}$

what a progress in this experiment!

However, look at Feynman diagrams in Figs. 1(a), 1(b) & 1(c) on page 1 of this article:

-- Figs. 1(b) & 1(c) are okay, but incomplete.
-- however, my main problem comes from Fig. 1(a) [to put it politely].



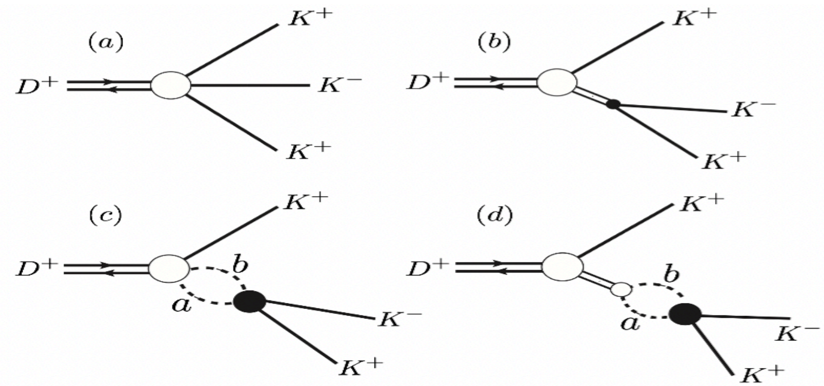
-- `WA' no chance to be the leading source !
-- `WA' <-> re-scattering (FSI) is *misleading* !

IIBigiV25

Connection of HEP with Hadrodynamics – true challenge!

One example in arXiv:1902.05884v3 [hep-ex] published in JHEP 04 (2019) 063

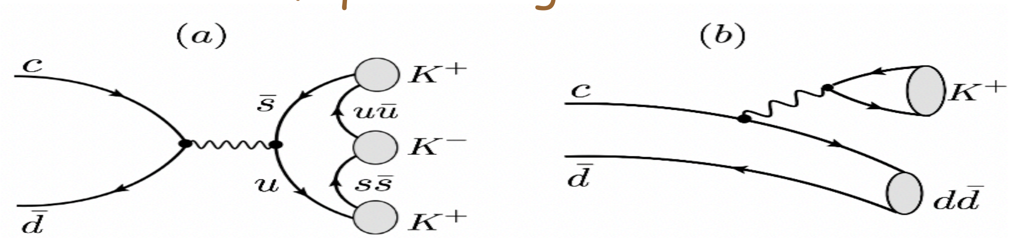
The world of hadrons



Nice `painting' !

Figure 10. Diagrams contributing to the amplitude T for the decay D+ → K– K+ K+: (a) the final state kaons are produced directly from the weak vertex; (b) a bare resonance is produced directly from the weak vertex; (c) particles produced at the weak vertex undergo final state interactions; (d) final state interactions endow finite widths to the resonances. The full circle represents the unitary ab → K+K– scattering amplitude with angular momentum J and isospin I, and ab = KK, ππ, ηπ and ηη.

The world of quarks & gluons

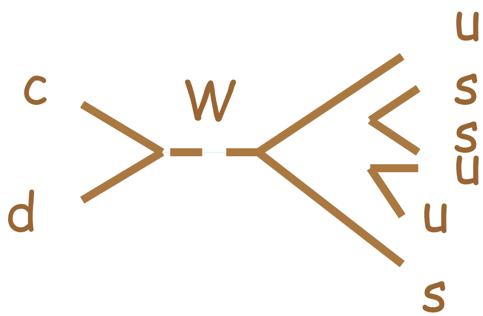


`WA' <-> re-scattering (FSI) is *misleading* or subtle about diagrams !

Figure 9. Diagrams representing the two quark-level topologies for the D+ → K–K+K+ decay. In the Triple-M [3], diagram (a) is assumed to be the dominant mechanism of the decay, whereas diagram (b) is suppressed since the production of a K+K– pair from a dd ̄pair requires rescattering.

(V.5) $\Delta C \neq 0$ with 3-body FS

LHCb for *DCS* decays, `Dalitz plot analysis of the D+ -> K+K+K- decay'
p. 12, `Figure 9 (a) is assumed to be the dominant mechanism …'
again



-- `WA' no chance to be the leading source !
-- `WA' <-> re-scattering (FSI) is *misleading* !

-- *cannot* ignore D+ -> K+π+π- !

(V.5) $\Delta C \neq 0$ with 3-body FS

LHCb for *DCS* decays, arXiv:1810.03138 [hep-ex] from 8 TeV;
arXiv:1902.05884v3 [hep-ex] from 8 TeV:

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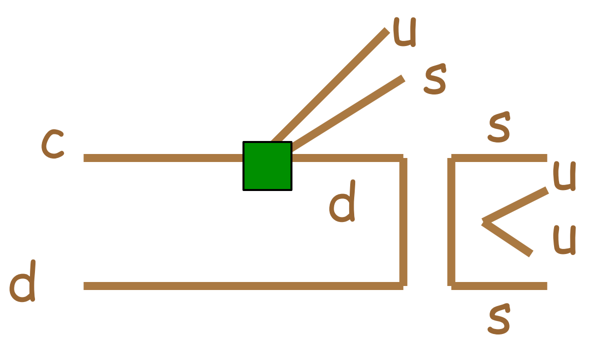
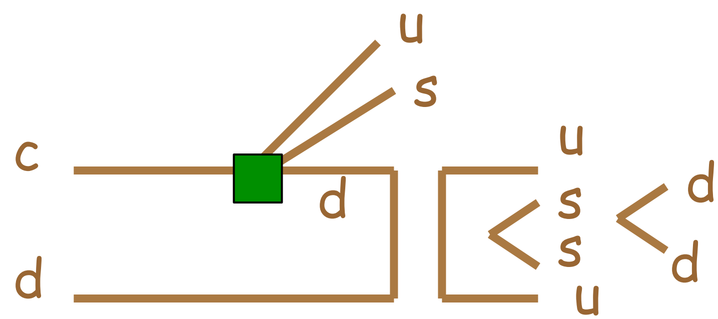
My `painting' of the amplitudes for D+ -> K+K+K-:





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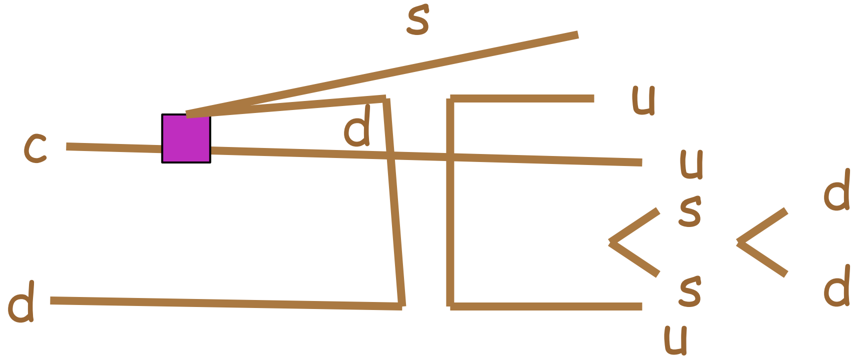

--`WA' <-> re-scattering (FSI)
is *misleading* !
-- effective chiral Lagrangian ! ?

IIBigiV25

(VI) Challenges for Beauty & Charm & Strange *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: *CP*V with 3.3 σ uncertainties with
- *regional* asymmetries ~ 20 % due to $[p\,\pi^-_{fast}][\pi^+\pi^-_{slow}]$!
- *Present* data & analyses about $[p\,\pi^-_{slow}][\pi^+\pi^-_{fast}]$?
  No predictions – we have to learn from the (re-fined) data !

-- 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

-- *no* information from *run-2* yet.

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

(VI.2.1) Lifetimes & SL widths of charm baryons

-- PDG2018: $\tau(\Omega^0_c) < \tau(\Xi^0_c) < \tau(\Lambda^+_c) < \tau(\Xi^+_c)$

in previous century one had expected this pattern based on HQE in a simple qualitative way.

-- PDG2019: $\tau(\Xi^0_c) < \tau(\Lambda^+_c) < \tau(\Omega^0_c) < \tau(\Xi^+_c)$

the situation has changed:

while the pattern $\tau(\Xi^0_c) < \tau(\Lambda^+_c) < \tau(\Xi^+_c)$ is the same, it has changed sizably for $\tau(\Omega^0_c)$; they depend on quark models, not just QFT.

Compare $\Lambda^+_c = [c(ud)_{j=0}]$ vs. $\Omega^0_c = [c(ss)_{j=1}]$

-- The goal is to measure `soon' SL widths of Ξ^0_c, Ξ^+_c, Ω^0_c.

There are connections based on non-perturb. QCD.

However these are subtle -- remember, Blazenka (Guberina & Melic)!

It is enough for one talk by itself.

(VI.2.2) CP asymmetries in weak decays of charm baryons

-- When one goes for CPV, one can*not* stop at 2-body FS: 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: $\Lambda^+_c \to p\, K^+\pi^-$
  - tiny rates are not the only challenge
  - compare DCS $\Lambda^+_c \to p\, K^+\pi^-$ vs. CF $\Lambda^+_c \to p\, K^-\pi^+$

(VI.3) Present and future lessons $\Delta S \neq 0$

-- We know that CP asymmetries has been found & established in the transitions of neutral strange mesons:

- *indirect* CPV in $K^0 \to 2\pi$ with the scale ~ 2.23×10^{-3} data
- *direct* CPV in $K^0 \to 2\pi$ with
  - ~ 3.6×10^{-6} data
  - < 2.2×10^{-6} SM ?!?
  - ~ 1.1×10^{-6} "Buras team" ["LQCD"]

  *

- amazing established of data & analyses
- it *might be beyond* the SM: "Buras team" ["LQCD"].

Buras is member of the Bavarian Academy

(VI.3) Present and future lessons $\Delta S \neq 0$

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*

- amazing established of data & analyses
- it *might be beyond* the SM: "Buras team" ["LQCD"].

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-- Next step for direct CP asymmetry in strange *baryons*

$e^+e^- \to J/\psi \to \Lambda\, \Lambda \to [p\, \pi^+][p\, \pi^-]$

- BESIII will probe CPV by 2018/19 with below 10^{-3}

-- duality violation enhanced close to thresholds ?

-- A novel `*road*'

Giovanni Punzi:

LHCb could do much better with *run-3/4 below* 10^{-4} !

*

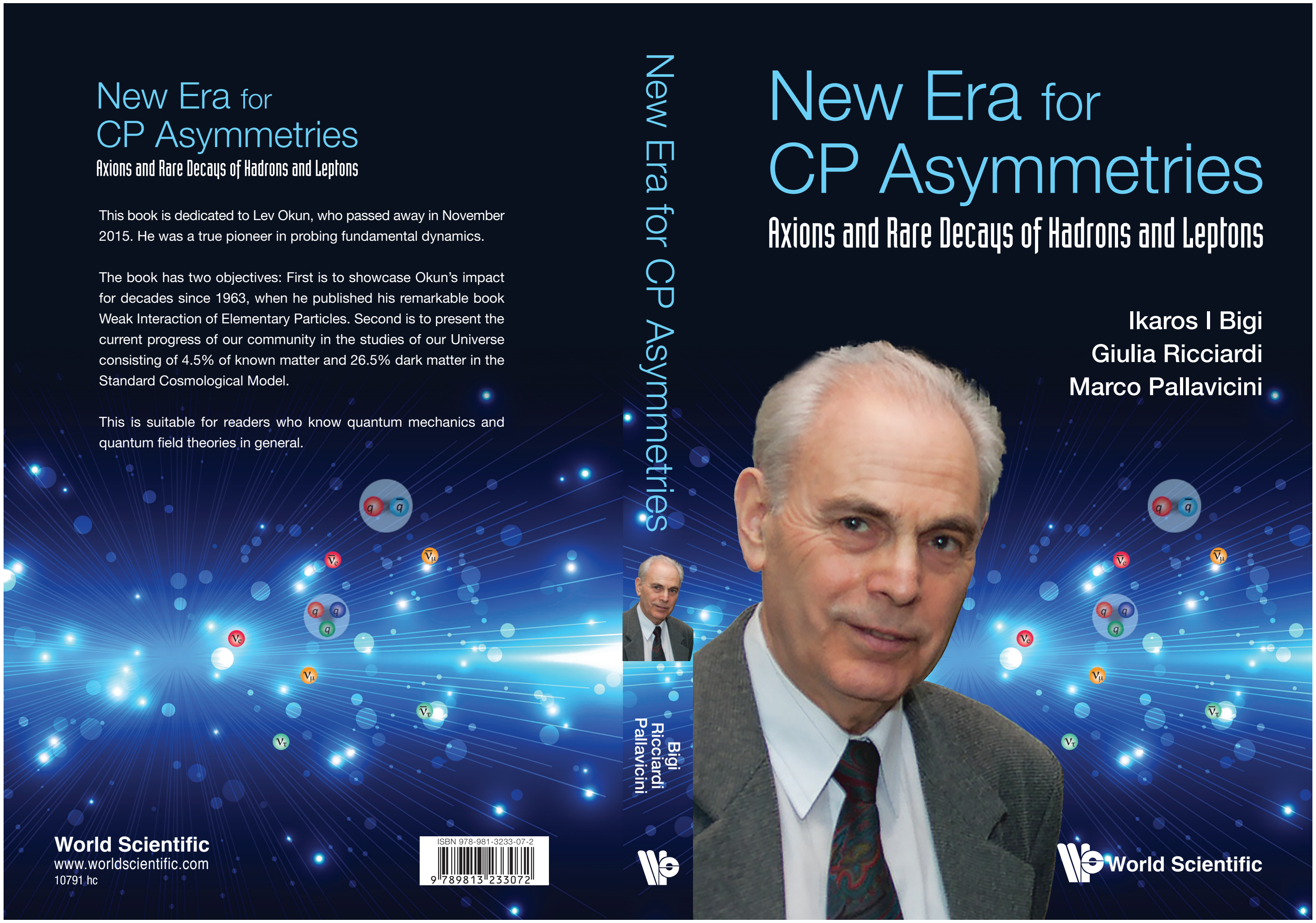
$J/\psi \to \Lambda\, \Lambda \to [p\, \pi^+][p\, \pi^-]$

- Some details: $J/\psi \to Y\, Y \to [X\, \pi]\, [X\, \pi]$ with a dedicated trigger

"Imagination created reality" – Richard Wagner

or: "dedicated trigger"

My new book will be published in the Winter 2019/20 dedicated to L. Okun



Epilogue for the future: *Collaboration* of HEP & Hadrodynamics

Need to connect the worlds of quarks & gluons with hadrons !

Back to the history outside

San Francesco, Arezzo (Italy)

Epilogue for the future: *Collaboration* of HEP & Hadrodynamics

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Back to the history outside -- & inside

San Francesco, Arezzo (Italy)

`The Dream of Constantine'
by Piero della Francesca,
painter of Early Renaissance,
mathematician/geometer

`dreaming in more dimensions'
Kolya Uraltsev & I had looked at this painting *in person* & realized that it is symbol of collaboration.

Epilogue for the future: *Collaboration* of HEP & Hadrodynamics

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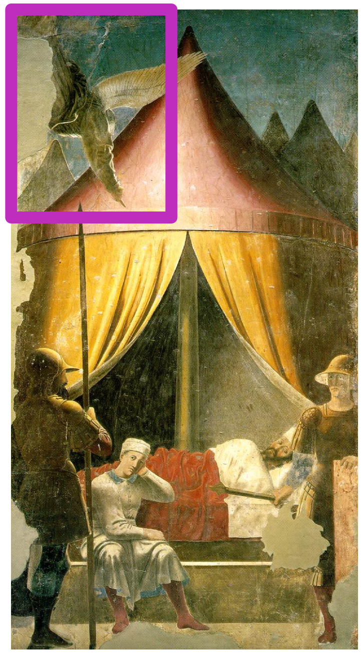

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`dreaming in more dimensions'
Kolya Uraltsev & I had looked at this painting *in person* & realized that it is symbol of collaboration.

-- history

NP → HEP

↑ flavor dynamics

-- now

NP → MEP/Hadrodynamics → HEP

↑ (to MEP/Hadrodynamics → HEP)
decays of strange/
beauty/charm mesons & baryons
Dalitz plots
dispersion relations
accuracy/precision

↑ (to HEP)
jets,
Higgs, top quarks
direct SUSY

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

- pions, kaons, ..., N, ... vs. quarks & gluons
    - 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

Future lessons for LHCb/Belle II

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

One example:

IIB & collab. (it is about bragging, but it *goes beyond*, namely HQE):

$\tau(\Lambda_b)/\tau(B_d) > 0.9$ 1993; ~ 0.94 & > 0.88 1996

Data: $\tau(\Lambda_b)/\tau(B_d) = 0.77+/-0.05$ 1996; 0.81+/-0.05 2004; 0.94+/-0.09 2005

(VII) Summary: Impact of *non*-perturbative QCD on *CP Violation*

about fundamental dynamics:

(a) Two-body FS do not give \`royal insights' in general;

(b) diagrams give no \`royal ones';

(c) Wolfenstein's parameterization of the CKM matrix is well-known & used all the time, but it is *not* \`royal ones' for *this* century;

(d) even less: pole masses give no \`royal insights' !

"Goals for *flavor dynamics* of quarks":

- ☞ Probing CP asymmetries in 3- & 4-body FS of charm & beauty hadrons is crucial to find both existence & features of ND. [At least it shows the impact of non-perturbative QCD.]
- ☞ Theorists do not like waiting: *results from run-2* !
- ☞ Waiting for run-3 & run-4: that is life.
- ☞ Worlds of quarks & gluons and for hadrons are connected, but often they are not obvious (\`duality' is more subtle than just looking at diagrams)!

-- `We' need more data, but that is not enough –
thinking & judgments about the impact of *long distance* QCD!

[-- HQET [with μ = 0] $\neq$ HQE [μ ~ 1 GeV]

HQET: `observables'= perturb. forces + non-perturb. forces

HQE: "observables" = "long-distance" forces +"short-distance "ones]

-- best fitted analyses do *not* give the best information about the underlying dynamics

-- CP asymmetries in 3- & 4-FS is crucial to make progress about ND

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

-- `Challenges between Cultures' of HEP vs. Hadrodynamics
like "current quarks" vs. `pole masses of hadrons'

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-- `Challenges between Cultures' of HEP vs. Hadrodynamics
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-- Difference between broken U- & V-spin is `fuzzy', and one has to go *beyond 2-body FS* !

-- New era of CPV has opened with $D^0 \to K^+K^-/\ \pi^+\pi^-$!

-- CP asymmetries have to be probed with beauty & charm baryons !

-- The theoretical situations of beauty & charm hadrons are quite different than for strange hadrons.

Back-up technical slides

-- Probing 3-body FS:

- Usual Breit-Wigner parameterization does not well describe the impact of broad resonances such as $f_0(500)/\sigma$, $K_0^*(800)/\kappa$ etc. Interference of narrow & broad resonances can*not* be described as being simply `inside' & `outside' the centers of the narrow resonance.

-- One can relate these items using non-trivial theoretical tools like chiral symmetries & refined dispersion relations based on data concerning low-enery pion & kaon collisions.

-- Again: *Collaboration* of HEP & Hadrodynamics !