2015 Standard Model Finale: Theory vs. Experiment

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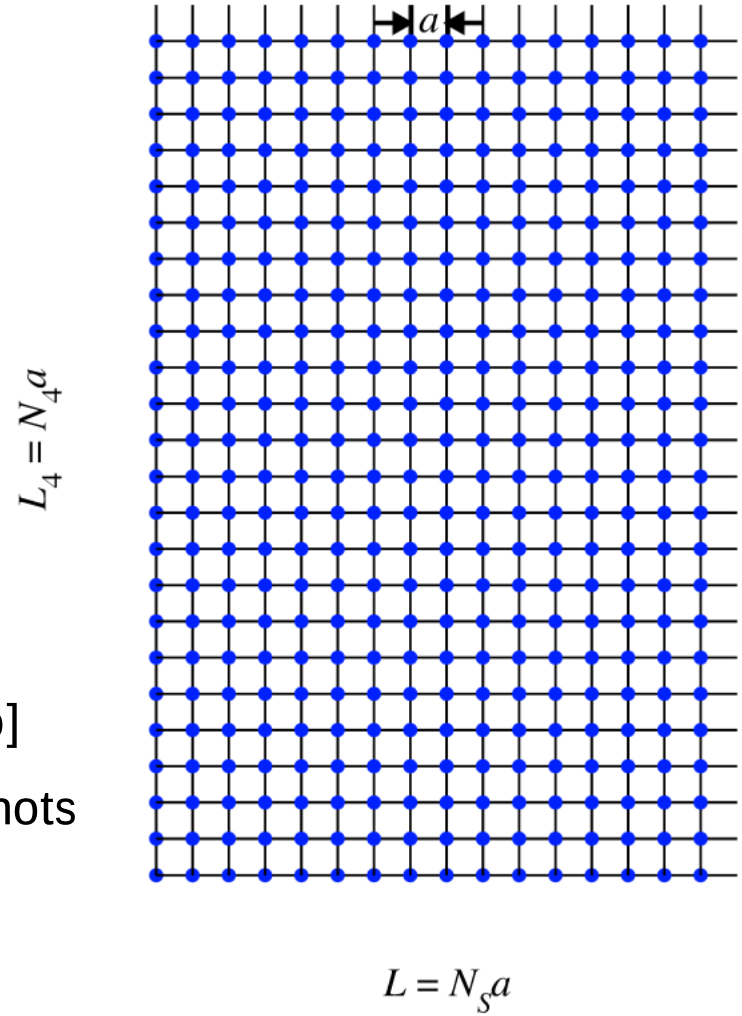
Brief History of Euclidian Time

- Lattice started in the 70s
- became a promising child of pure theory
- and never had a hope to grow up
- and do anything quantitative
- but it has proved the *asymptotic freedom*
- and demonstrated *confinement*
- basically proven that QCD is *the theory of strong interactions*
- but in ’83 K.Wilson suggested that we would need lattices of 256x512
- before it is quantitative
- while we still run 48x96
- *So, how are we doing?*

Brief History of Euclidian Time

$$\langle \bullet \rangle = \frac{1}{Z} \int \mathcal{D}U \; \mathcal{D}\psi \, \mathcal{D}\bar{\psi} \; \exp(-S) \, [\bullet]$$
$$= \frac{1}{Z} \int \mathcal{D}U \det(\not{D} + m) \exp(-S) \, [\bullet']$$

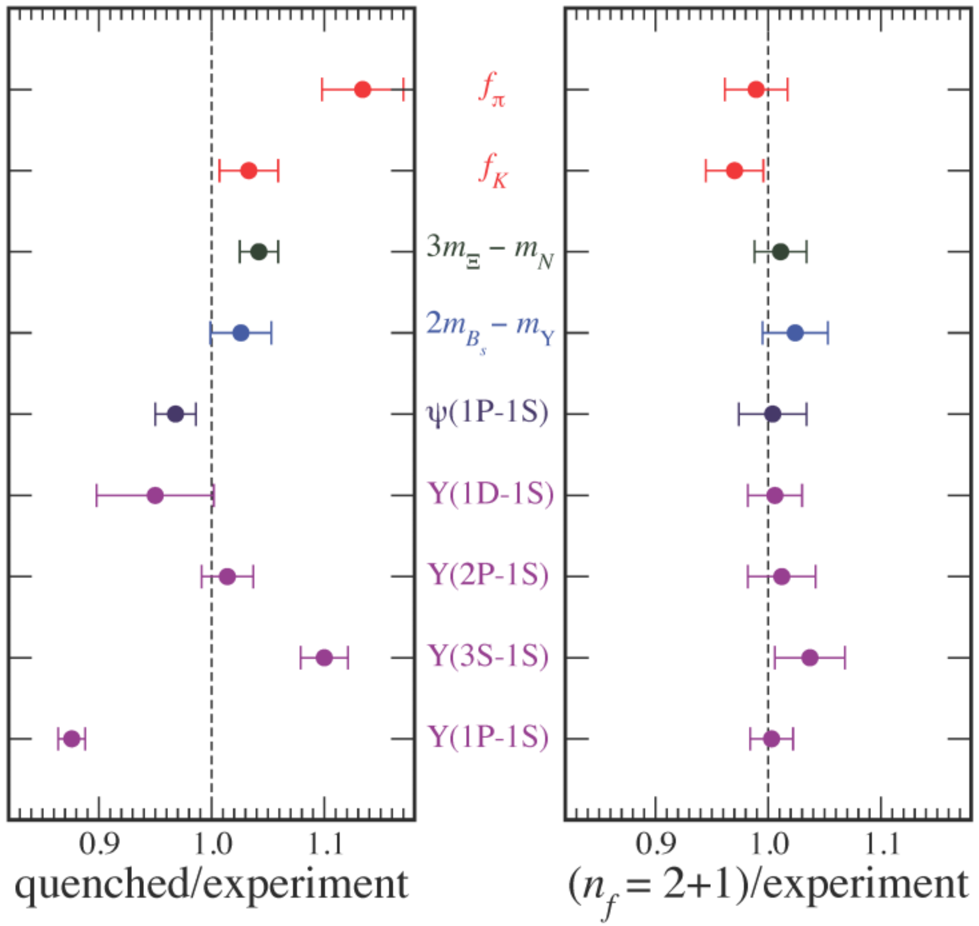
- start from a random system
- formulate rules for the evolution
- based on the physics you want to study
- go drink coffee for a month [or a year][or two]
- you will have hundreds of independent snapshots
- of what you think is a real world



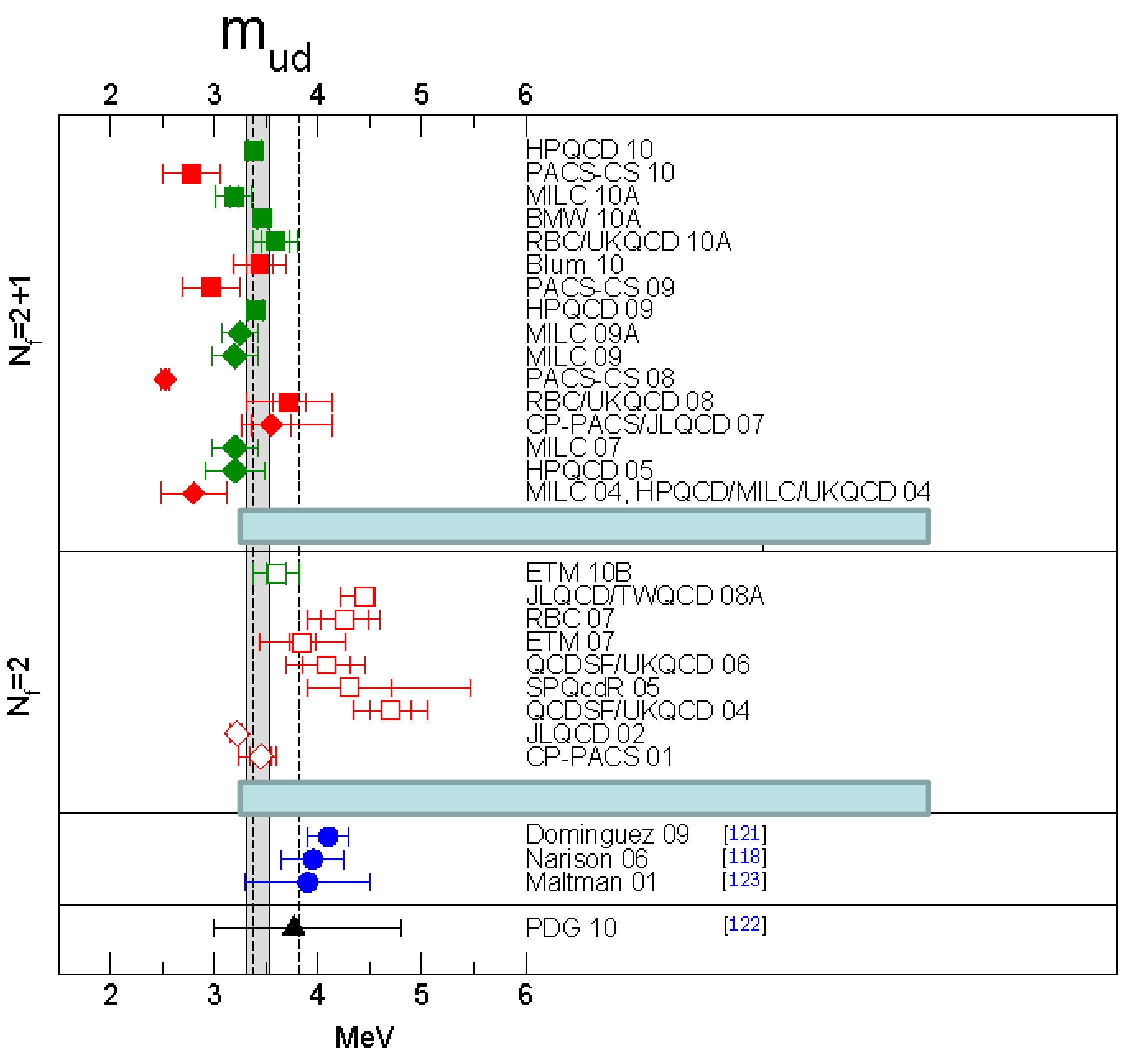
Brief History of Euclidian Time

- and if you have a GigaFlops
- you get the left plot
- in about 5 years

- and if you have a TeraFlops
- you get the right plot
- in about the same amount of time

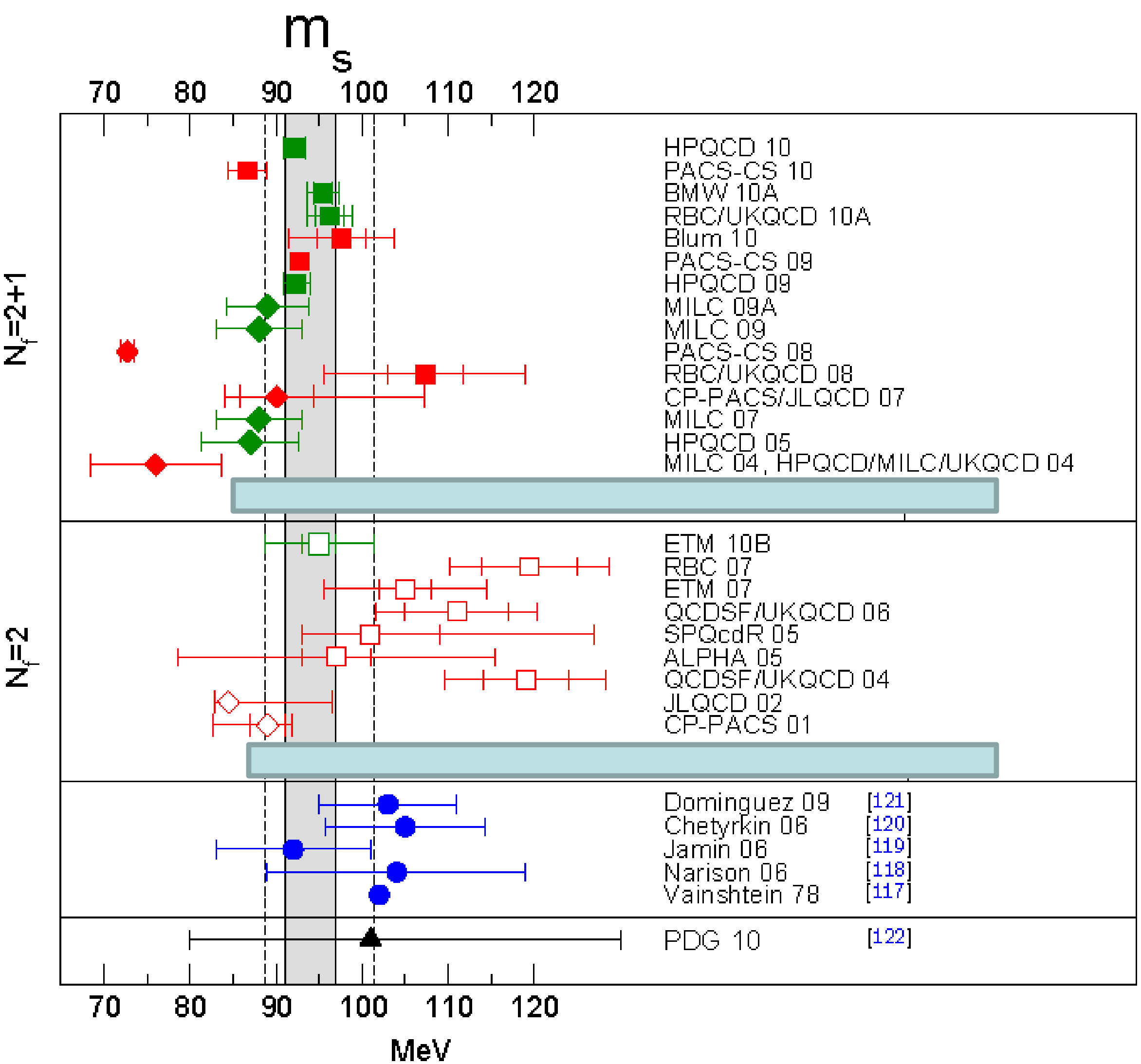


Sweet smell of success



- picture from the FLAG
- where I removed FLAG averages
- because it is not a statistical ensemble
- so we are winning this round
- but is there something strange?

Sweet smell of success



- no, with the strange

  it is even better
- even in the case when

  we ignored loops

  involving it

so I guess we can all go

home?

Road to Success

- Free Lunch, also known as Moore’s Law
- Exponential growth of computer power
- Which we also helped with custom-build computers
- **APE100** to **APEMille** to **APENext** to **QPACE** to **AuroraSCI**
- **QCDSP** to **QCDOC** to **BlueGene** (yes, bluegene)
- GigaScale to TeraScale to PetaScale
- ...and using every available piece of hardware

Road to Success

- But even that cannot compensate cruelty of Nature
- The “Berlin Wall” in 2001 was a demo of exponential growth
  of effort while reaching continuum and physical masses
- So the algorithmic work intensified and made it **linear**
- while shaving off a **factor of 100**
- and the “wall” crumbled, as walls tend to do
- but how much of a success is it?

The Battle for Unitarity

the first row

$$\begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix}$$

$$V_{ud}^2 + V_{us}^2 + V_{ub}^2 = 1$$

the highest precision attained

studied from Kaon decay

and the lattice gives the f_K / f_π and $f_+(0)$

The Battle for Unitarity

the first row

$$\begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix}$$

V_{ud} / V_{us} from $K \to l\mu / \pi \to l\mu$

$$\frac{\Gamma(K \to \mu)}{\Gamma(K \to \pi)} \sim \frac{|V_{us}|^2}{|V_{ud}|^2} \left(\frac{f_K}{f_\pi} \right)^2$$

V_{us} from $K \to \pi l$

$$\Gamma(K \to \pi) \sim |V_{us}|^2 |f_+|^2$$

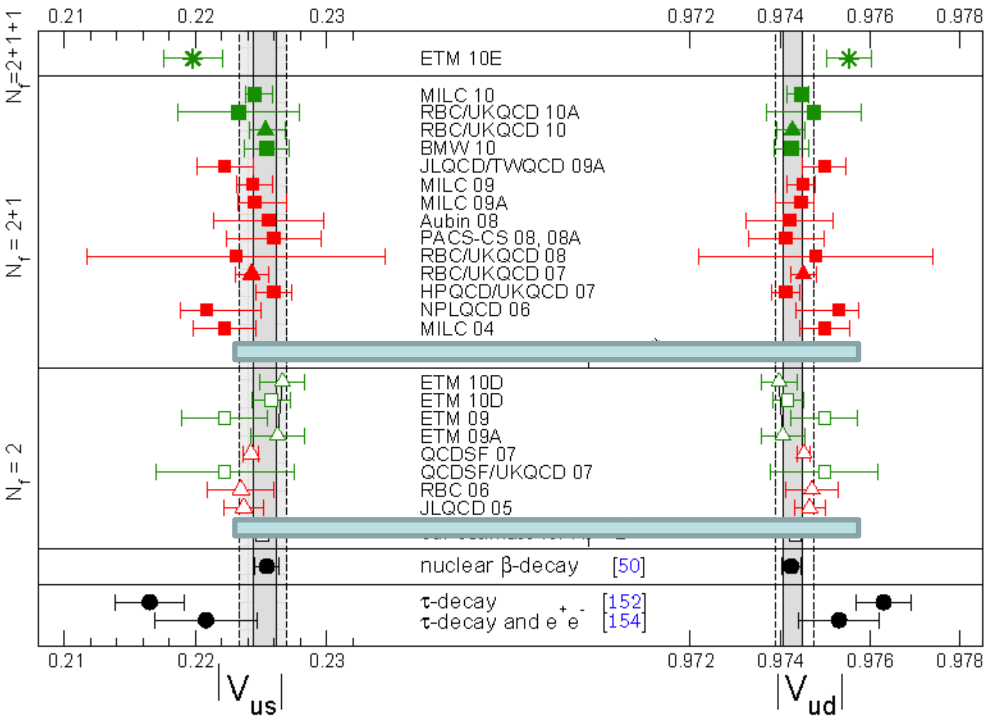
The Battle for Unitarity

the first row

$$\begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix}$$

$$|V_{ud}| = 0.9743(6)$$

$$|V_{us}| = 0.2254(18)$$



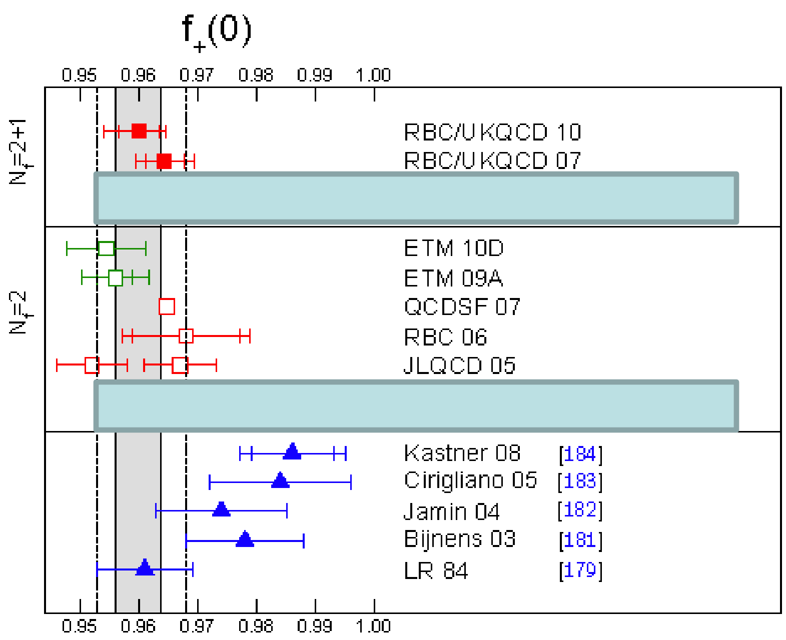
The Battle for Unitarity

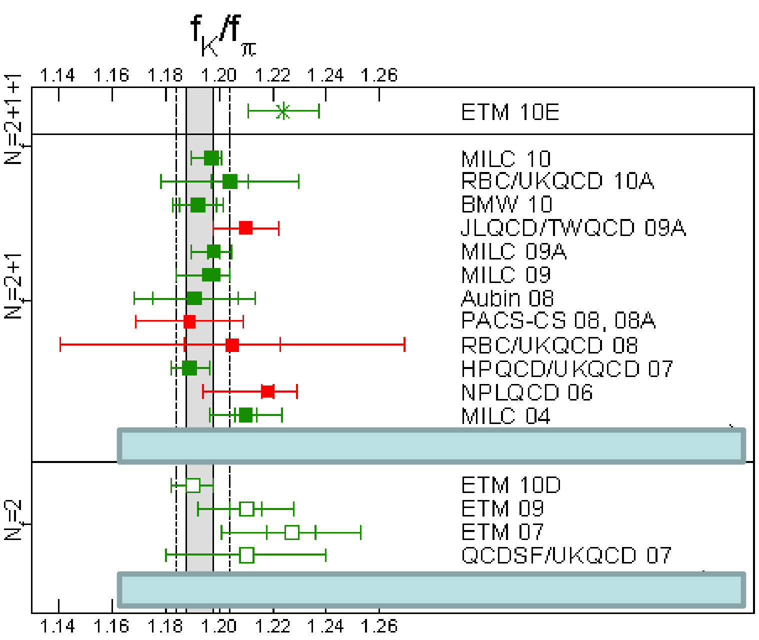
the first row

$$\begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix}$$

$$\left| f_+(0) \right| = 0.96(1)$$

$$\left| f_K / f_\pi \right| = 1.20(2)$$



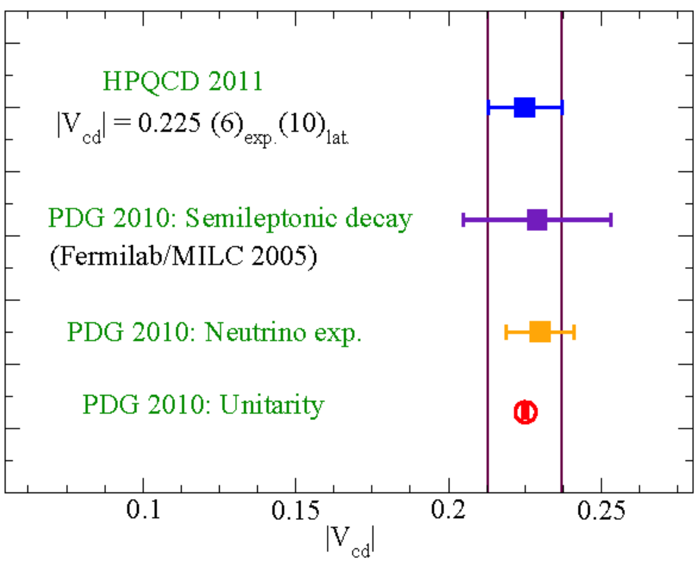


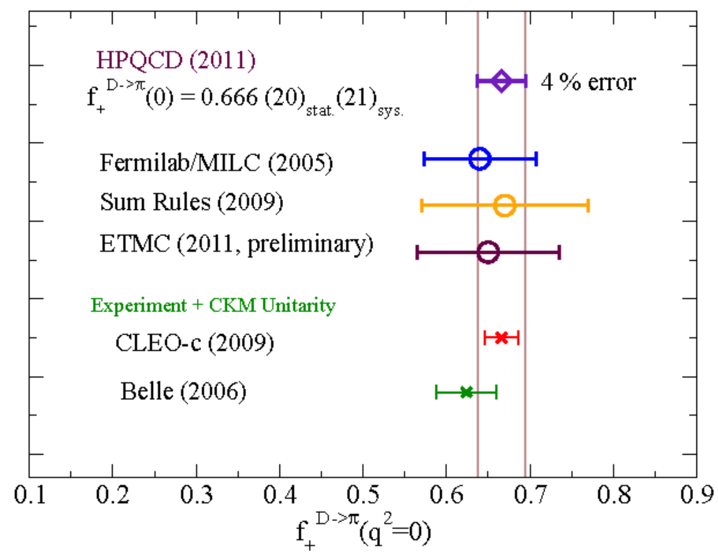
The Battle for Unitarity

second row

$$\begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix}$$

$$V_{cd}^2 + V_{cs}^2 + V_{cb}^2 = 0.976(50)$$

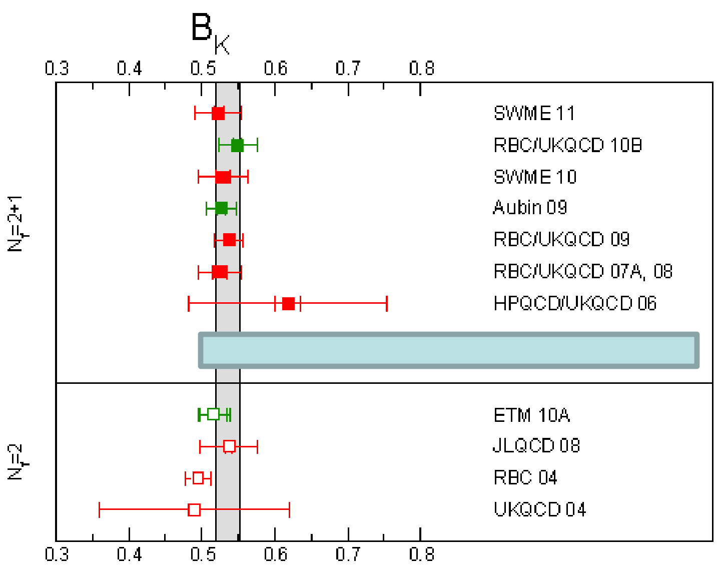


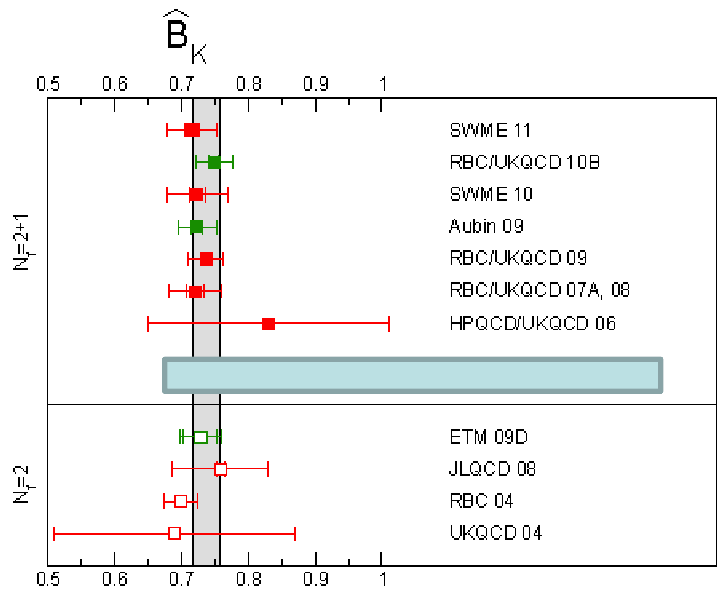


Heavy Weighters

challenges of B-physics

- We cannot simulate B-quarks directly
- Because they literally fall thru the cracks in the lattice
- that is $m_b \sim 1/a$





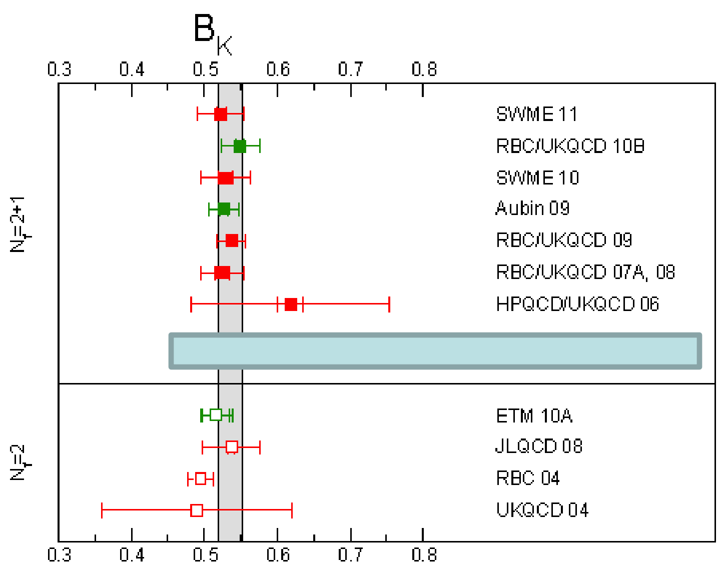
Heavy Weighters
challenges of B-physics

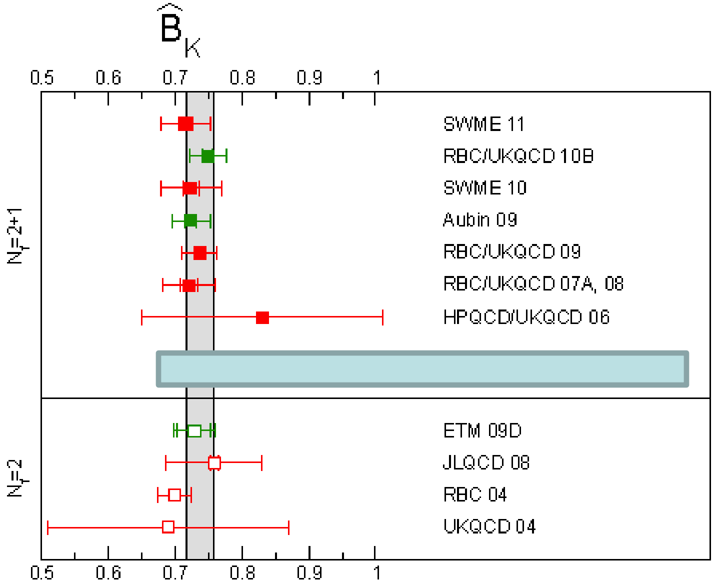
- So how did all these fine results happen?
- Fermilab way: formulated for charmonium
- Break space-time symmetry, do a RG analysis
- Expand in a small parameter
- Works like magic for the c-quarks
- But when you try to do it for bottomonium...
- you will find out, if you check ...
- ... that the expansion parameter is not so small

Heavy Weighters

challenges of B-physics

- Most other people: pretend that b-quark is infinitely heavy
- so that is cannot move at all
- which is called HQET, the heavy quark effective theory





Heavy Weighters
challenges of B-physics

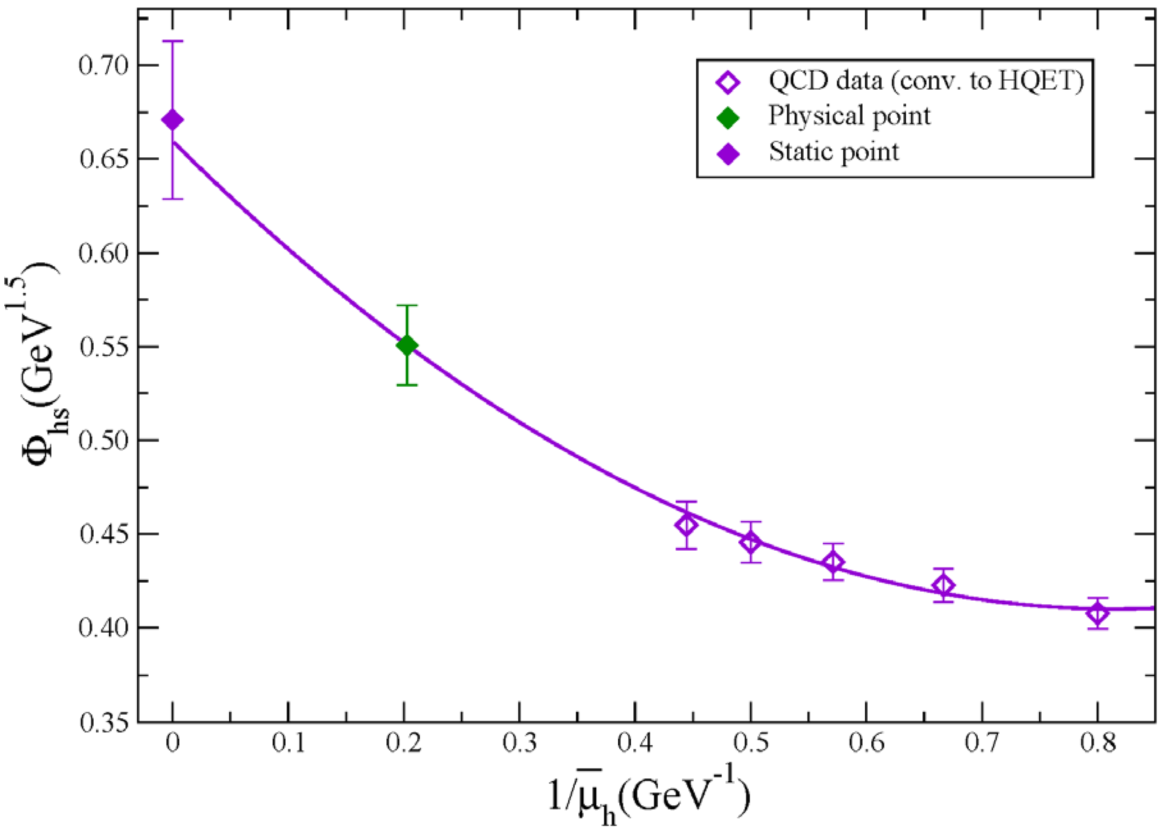
- The problem with HQET, Fermilab, NRQCD etc
- is that they are not controllable approximations
- we can neither predict the systematic error from them
- nor gradually improve them

- so it makes lattice QCD look a bit like a ... model

- while we take pride in being a theory.

Heavy Weighters
challenges of B-physics

so let us do it differently (ETMC)



Apples and Oranges

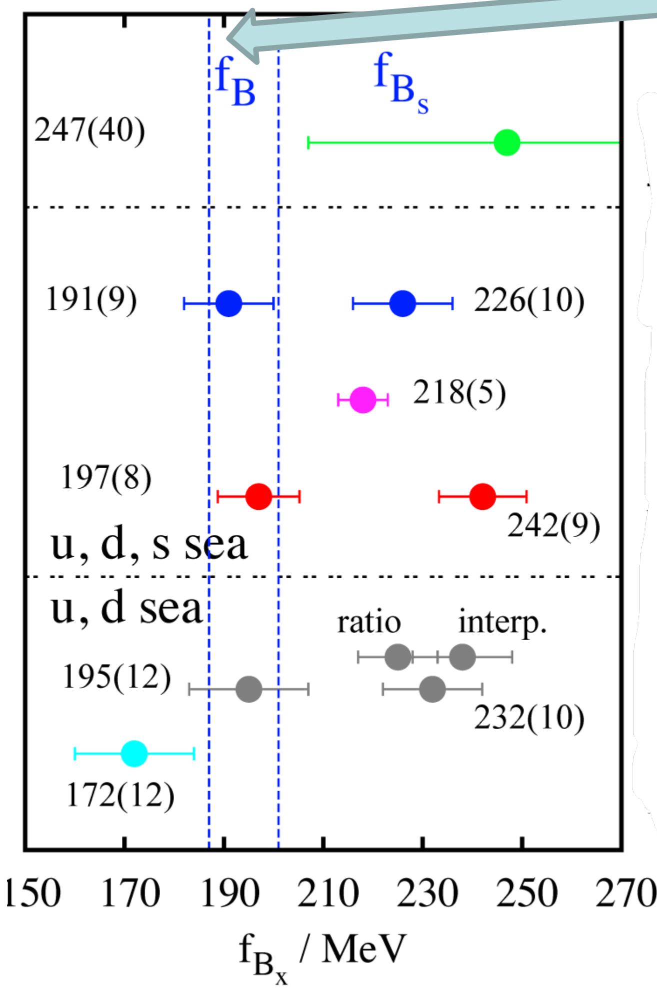
Why we really cannot average over results from different groups

source	HPQCD	FermiMilc
Statistical	0.7	3.4
Scale	1.1	1.4
Chiral	0.3	2.8
Heavy mass	0.2	2.6+3.9
Light mass	-	2.1
Operator matching	4.0	-
Relativistic corrections	1.0	-
Renormalization	-	3.1
Total	4.4	8.8

Heavy Weighters

challenges of B-physics

So you might think this has any meaning.
But most likely not.



PDG $B \to \tau\nu$ combined with PDG Vub

HPQCD (NRQCD)

HPQCD (HISQ)

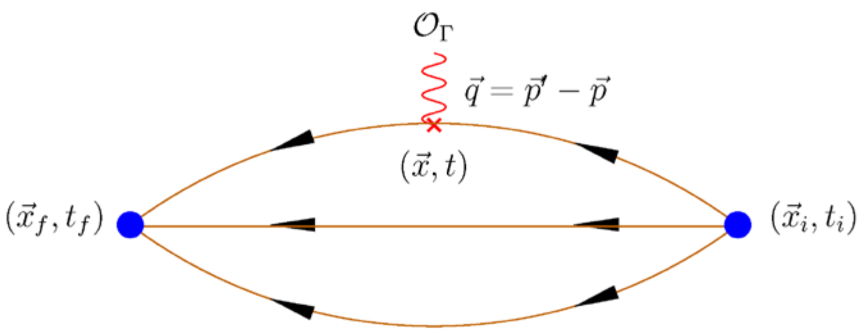
FNAL (Fermilab)

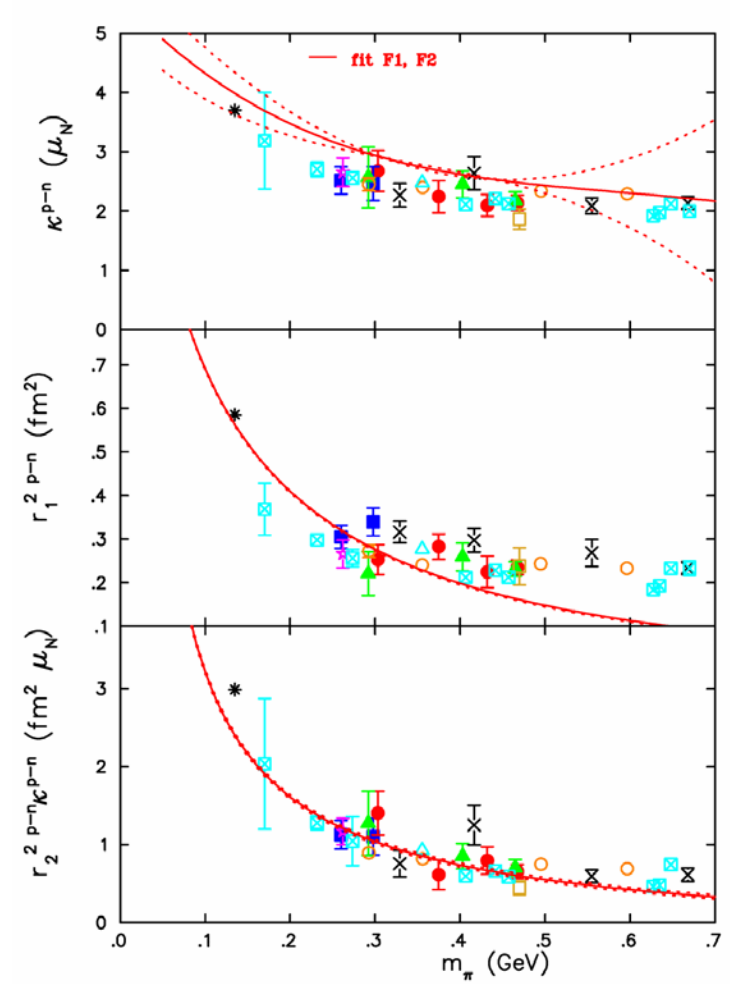
ETMC

ALPHA

Triplets from Protonville

short look at baryon physics





- requires large statistics – in **3pt functions**

  it is mandatory to vary all t_i
- so we are looking at **15k inversions** or so
- and for many quantities we need “**disconnected**

  diagrams”... thousands of inversions more
- also, we are obviously in the region of way too high

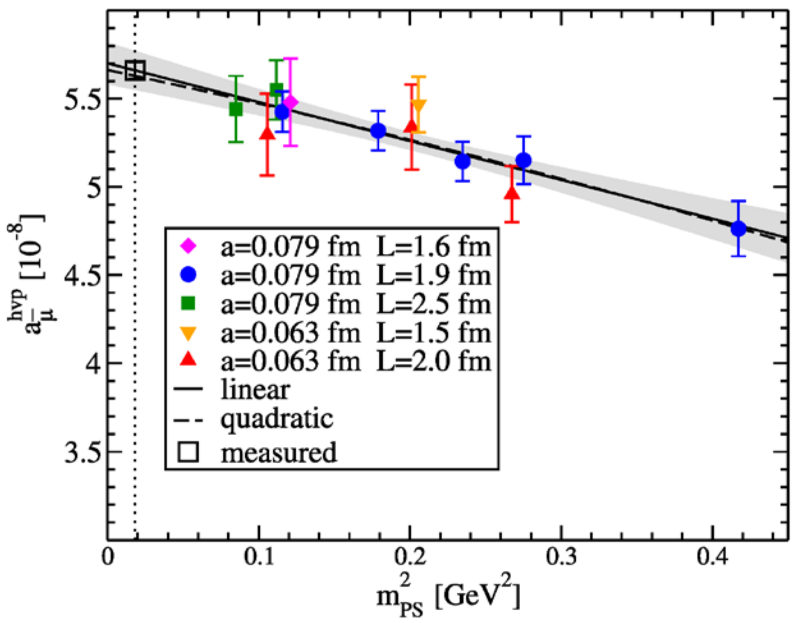
l light quark mass

Searching for New Physics

g-2: Vacuum polarization

Jansen et al/ETMC

- sometimes miracles happen and we can find RG argument to approach continuum/physical point faster
- so the muon contribution to vacuum polarization is easy and stable
- same applies to the electron and tau
- and the main contribution to the g-2, vacuum polarization we have already



- But the next contribution, the Light-by-Light, requires 3pt functions
- and on top of this, the disconnected diagrams
- so situation is as dire as for previous slide

Into the future

Cans and Can’ts

Improvement:	**Verdict**
Statistics	Yes, we can do that with current CPU power
Physical Quark Masses	Can (Clover-Smeared) Cannot (Twisted Mass, Clover, Wilson)
Closer to continuum limit	Can (give us petaflops) Cannot (Idris-Cines-Curie)
B-Quarks physical	Can (give us 10 petaflops) Cannot (not in europe)
Disconnected Diagrams	Can (GPUs will save us) Cannot (See following slides)
Better Renormalization constants	Can (currently done at LPT/Orsay) Using hardware at CEA/IRFU

Into the future

end of free lunch

- Moore’s Law is over. Quantum mechanics is cruel.
- Now we have amended law, that computer power **per watt** doubles
- which is great for the environment, but a **slow death** for lattice
- as if it was not enough, other sciences learned to use our computers
- so from **50%** on Idris, Cines etc
- we are down to **10%**
- which is great for the other sciences as then can finally become actual sciences
- but not so great for particle physics
- and this happens in many places. So how do they solve this problem?

Into the future

Regional Cuisine

Area	Activity
USA	$24.000.000 investment in the machines for LQCD till 2015 Already access to BlueGene/Q At IBM TJ Watson Centre, soon BG/Q in Brookhaven, Argonne, Livermore GPU clusters in JLAB Fermilab Livermore NCSA
UK	800 Tflops (200 Sustained) of BG/Q in Edinbourgh, for lattice and astrophysics
Japan	10% of World's fastest K-computer is for lattice QCD
Allemagne	Munich CC upgrading to 100k cores GSI, Frankfurt, DESY, Bonn have big GPU Farms
France	Umh… we got new CC building in Lyon CURIE is pointless, Curie-Hybride is not so bad
Others	Who are the others?

Into the future

Gastronomie Francaise: Preparation

- Major assumption is that new architectures will arrive
- And once it happens, there is usually a gap of 2-4 years

  before astro-bio people learn to use it
- So we need to streamline the upgrade of the code from old to new
- but how can one do it with so many Lagrangians and so many algorithms?
- and so few PhD students?
- USA has SciDAC, France has PetaQCD
- which wants to make PhD students to do physics,

  and not assembly programming

High Level Description

- Natural to do in LaTeX. Because we do everything in LaTeX.
- Requires some care, pre-defined syntax
- But can be immediately compiled into readable form using LaTeX
- Definitions: provides a set of identities or definitions to matrices, later used
- Templates: define methods for computation of expressions matching a template
- Goal: defines the starting code (in high level) we want to transform,
- and the list of methods to transform it.

High Level Description

Constant: $Dirac, P_e, P_o, \gamma_5, iQ \in M, \text{Preconditioner1}(,)\text{Preconditioner2}(\in)M- > M, \gamma, \sigma, g_a \in Index- > M, U \in Index- > Index- > M, \kappa, \mu, \epsilon \in \mathbb{C}, D \in Indexset, dx, dy, dz, dt \in Index$

Input : $c \in \mathbb{C}, d1 \in Index, s1 \in Index$

Var : $s \in Index, d \in Index$

$$Dirac = I_{L \otimes C \otimes S} + ((2 * i * \kappa * \mu) * (I_L \otimes I_C \otimes \gamma_5)) + \sum_{d \in D} (J_L^d \otimes I_{C \otimes S}) * \bigoplus_{s \in L} U(d, s) \otimes (I_S + \gamma(d)) \quad + \sum_{d \in D} (J_L^{-d} \otimes I_{C \otimes S}) * \bigoplus_{s \in L} U(-d, s) \otimes (I_S - \gamma(d))$$

$$P_e = P_{even,L} \otimes I_{C \otimes S}$$

$$P_o = P_{!even,L} \otimes I_{C \otimes S}$$

High Level Description

$$
\begin{aligned}
U(-d1, s1) &= U(d1, s1 - d1)^\dagger \\
\text{Preconditioner1}(Dirac) &= Pe \\
\text{Preconditioner2}(Dirac) &= Po \\
\gamma(d1)^\dagger &= -\gamma(d1) \\
\sigma(-d1) &= -\sigma(d1) \\
g_a(d1) &= i * \gamma_5 * \gamma(d1) \\
\text{invertible}(I_S + c * \gamma_5) &= true \\
\text{invertible}(I_S - c * \gamma_5) &= true \\
\text{type}(\gamma(d1)) &= S \times S \\
\text{type}(\sigma(d1)) &= HalfS \times HalfS \\
\text{type}(U(d1, s1)) &= C \times C \\
\text{type}(\gamma_5) &= S \times S \\
\gamma_5^\dagger &= \gamma_5 \\
D &= \{dx, dy, dz, dt\}
\end{aligned}
$$

Algorithm:

Conjugate Gradient

Input : $A \in M, b \in V$

Output : $x \in V$

Match : $x = A^{-1} * b$

Require : $A^{\dagger} = A$

Var : $r, r_1, Ap, p \in V, \alpha, \beta, n_r, n_{r1} \in \mathbb{C}$

$r = b$;

$p = r$;

$n_r = (r \mid r)$;

while $(n_r > \epsilon)$ **do**

$Ap = A * p$;

$n_r = (r \mid r)$;

$\alpha = n_r / (p \mid Ap)$;

$x = x + \alpha * p$;

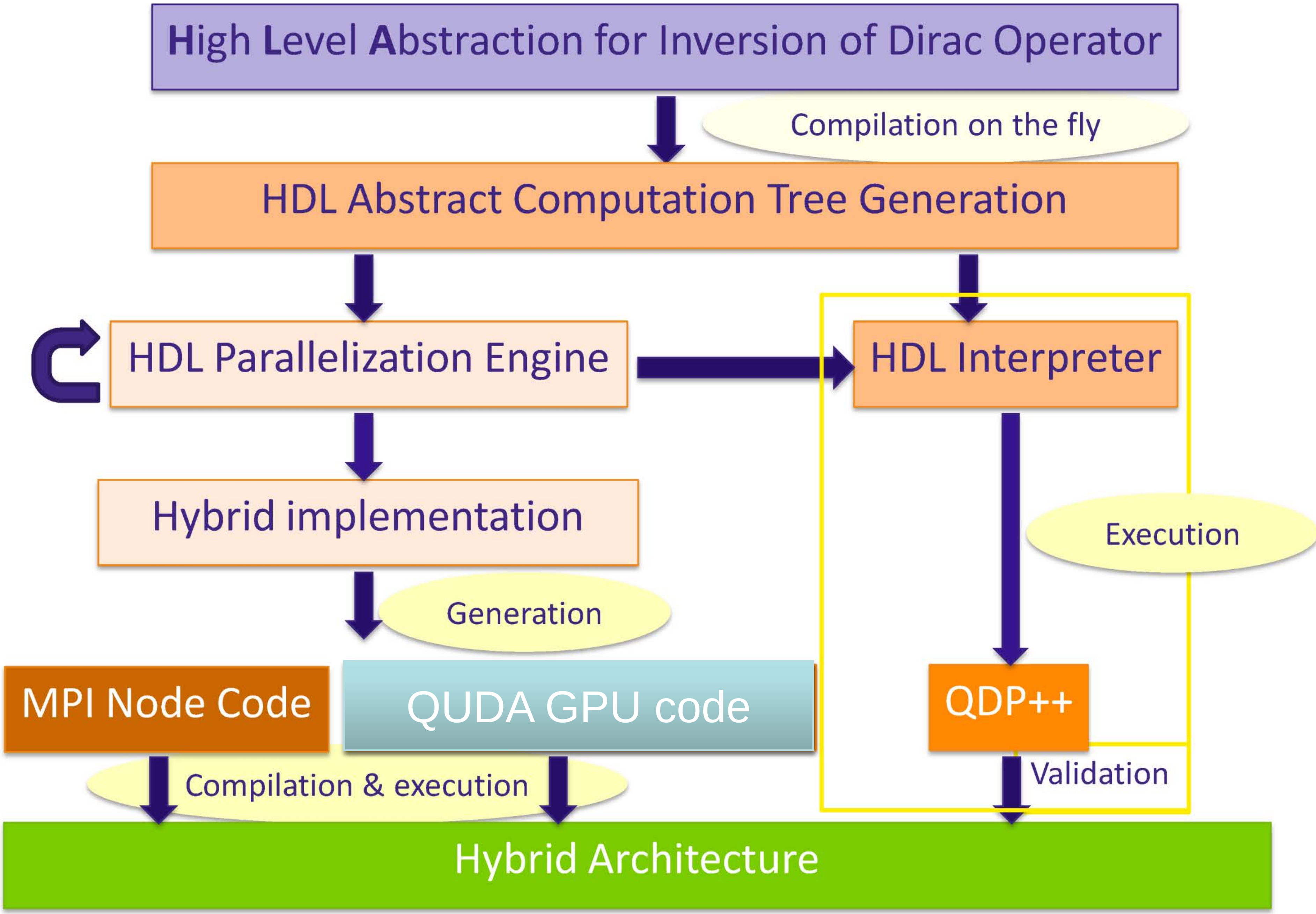
$r = r - \alpha * Ap$;

$n_{r1} = (r \mid r)$;

$\beta = n_{r1} / n_r$;

$p = r + \beta * p$;

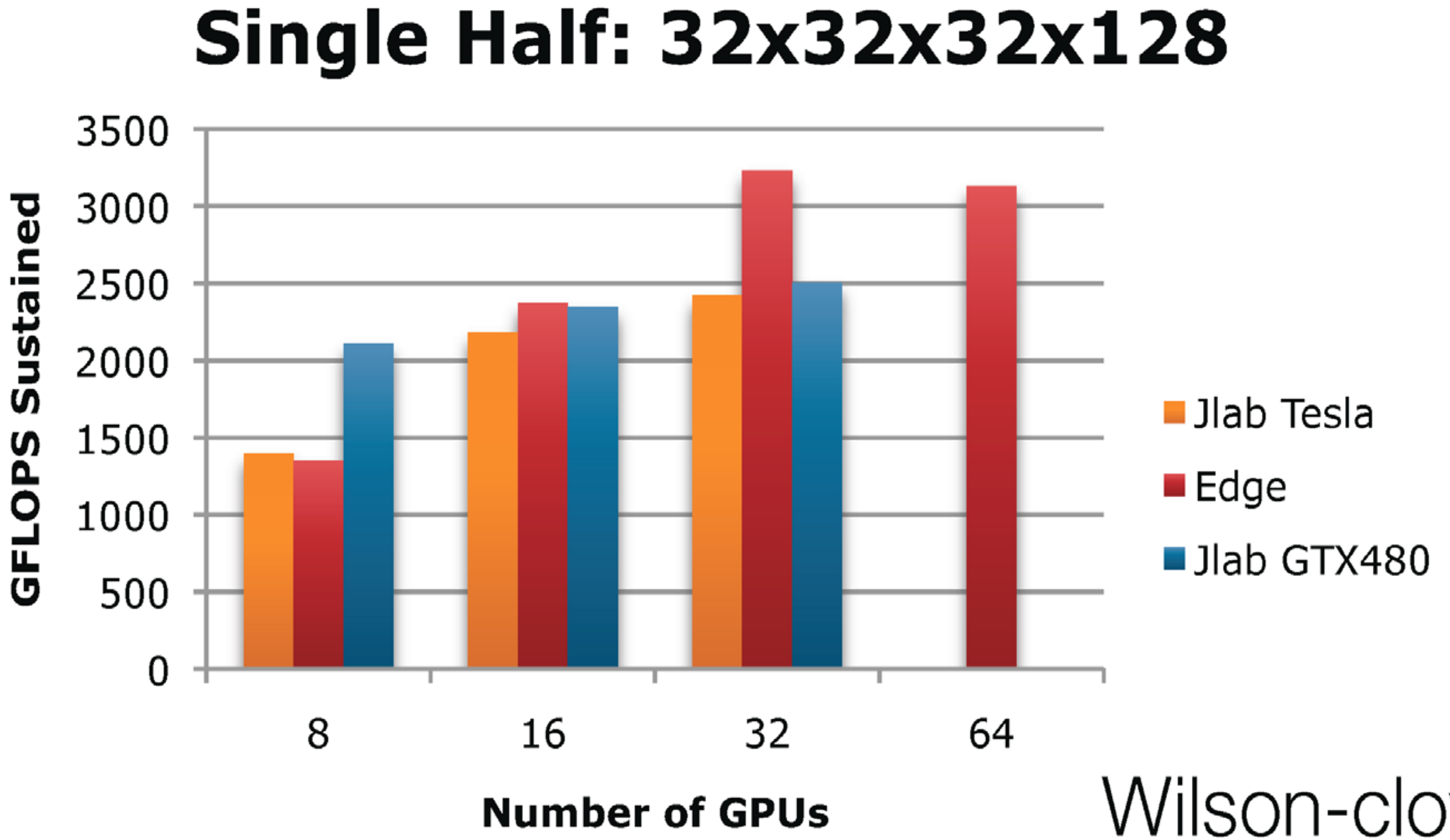
$n_r = n_{r1}$;


High Level Abstraction for Inversion of Dirac Operator
Compilation on the fly
HDL Abstract Computation Tree Generation
HDL Parallelization Engine
HDL Interpreter
Hybrid implementation
Execution
Generation
MPI Node Code
QUDA GPU code
QDP++
Compilation & execution
Validation
Hybrid Architecture

It takes two to Tango

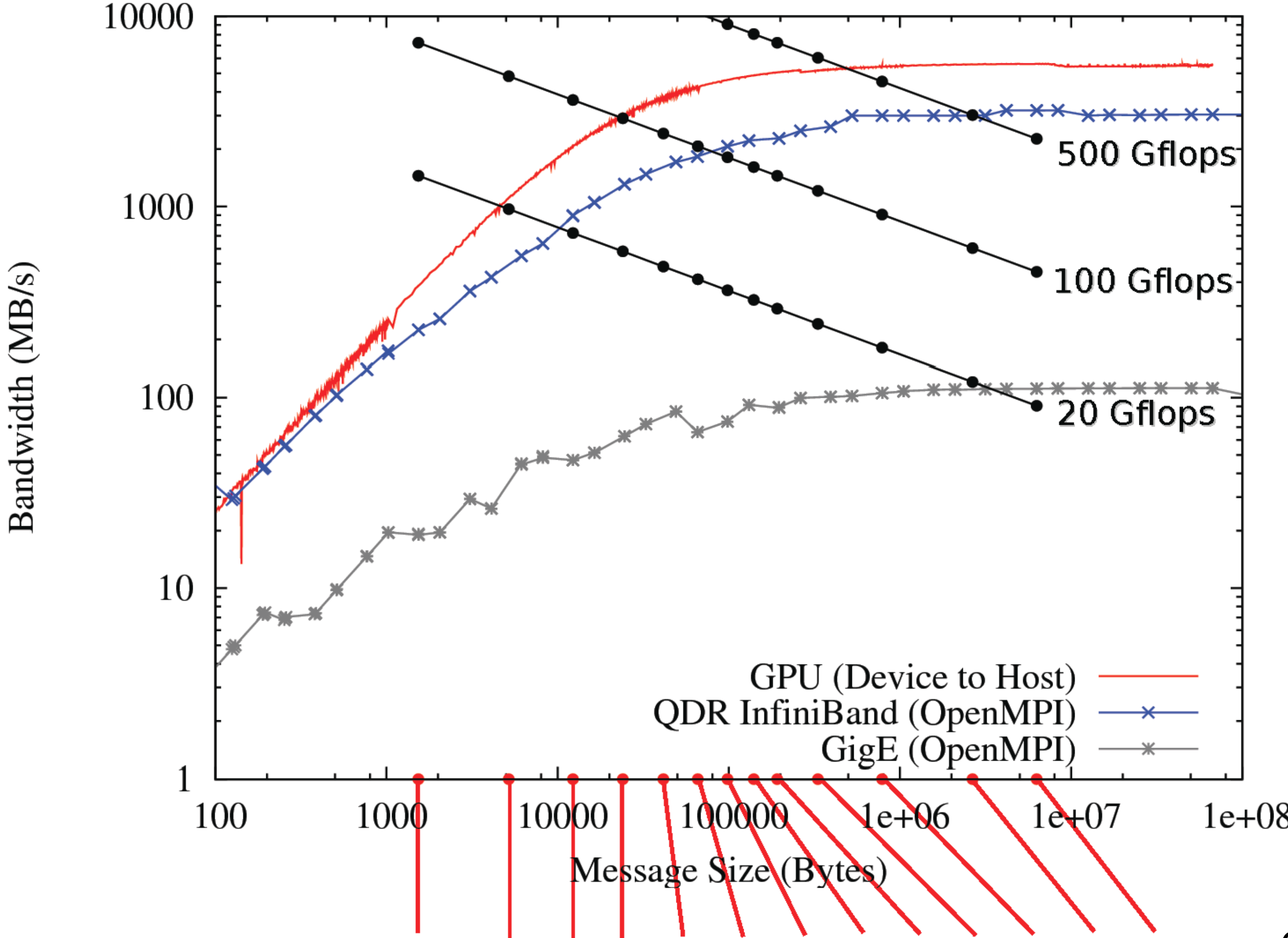
- the advances in software are pointless without hardware to run it on
- currently the architectures of Intel stagnate for any memory-bound applications
- that is on CURIE in CCRT/CEA we can shut off half of the cores and have the same performance
- because ultra-multi-core technology only benefits LINPACK
- Same applies to GPU clusters
- Each GPU is a genius, but they now cannot do any team work
- So typical closely-coupled problem will spend about 80% in waiting
- and all the quoted teraflops have no relation to real-world applications
- so let us improve hardware

State of Things: Scaling of the Inverter



Wilson-clover

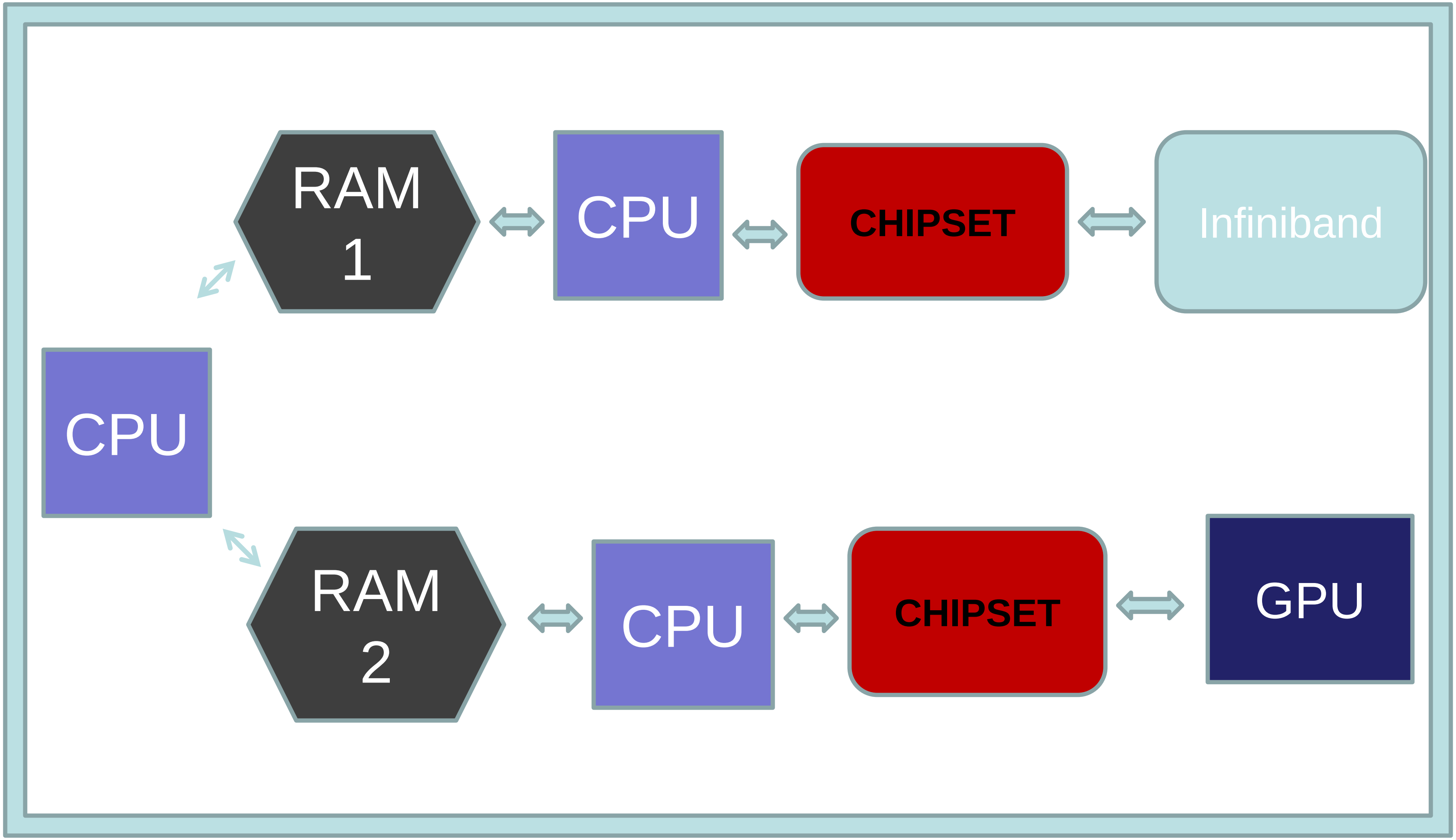
Modelling MultiGPU Performance



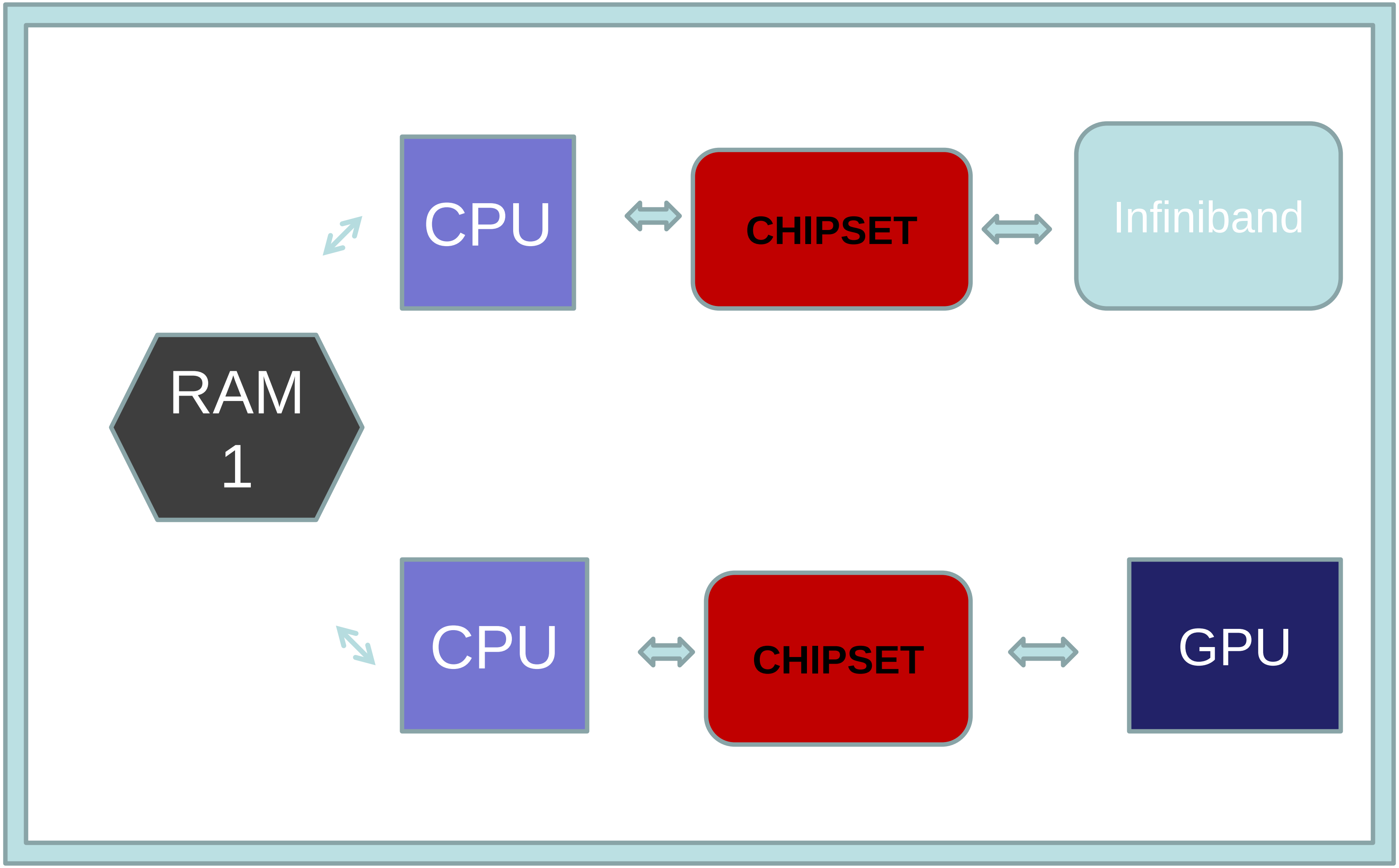
L = 4, 6, 8, 10, 12, 14, 16, 18, 20, 24, 32, 48, 64

Clark'11

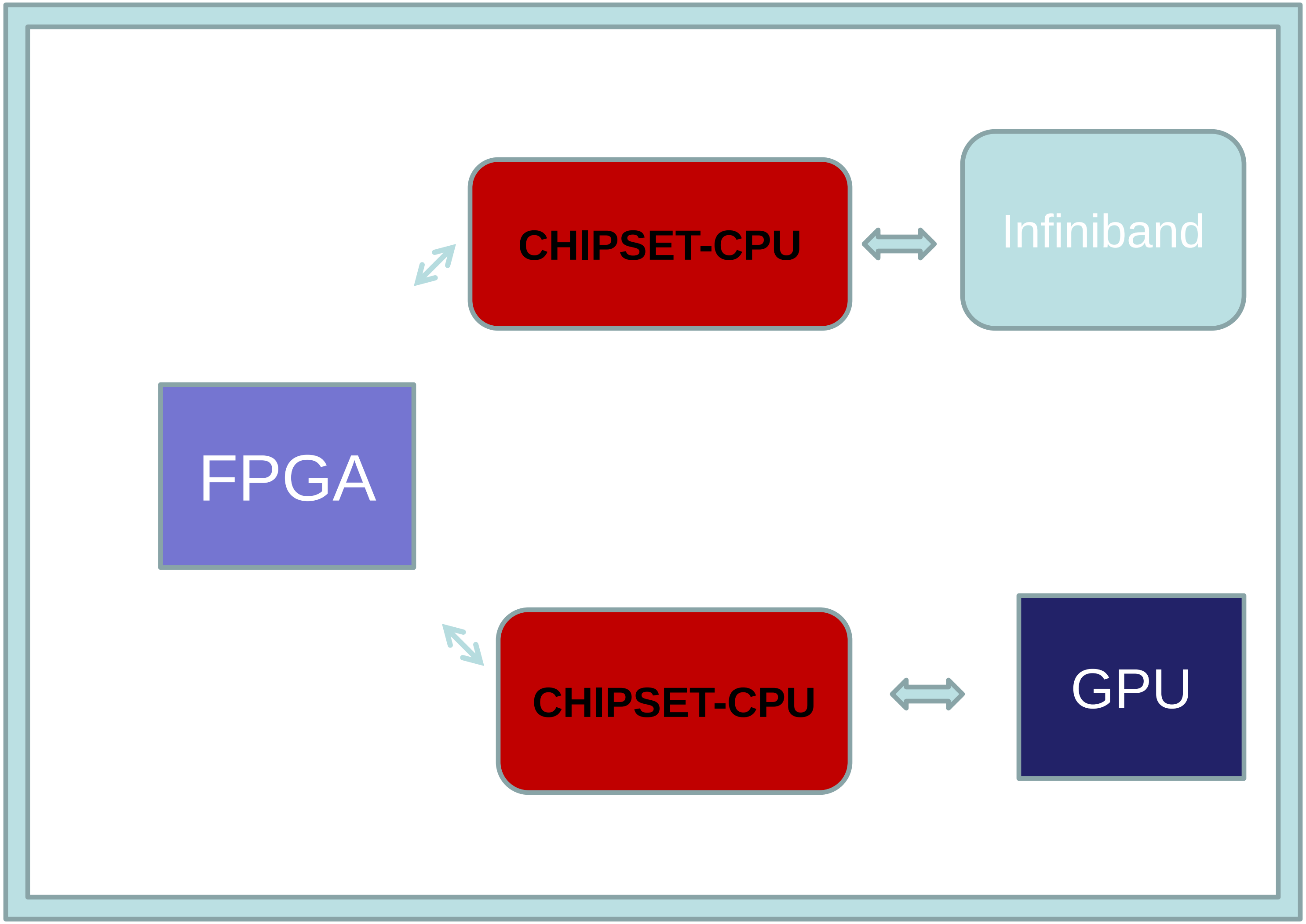
Old way



Current way



New way



Implications

- Both development and production of the prototype/supercomputer

  cost both money and manpower
- If neither this, nor substantial BlueGene/Q happens
- There won't be any significant improvements on this side of Atlantic
- UK/US/Japan will be the only ones with light u/d masses, heavy b-masses

  (if Republicans still loose the election)
- So questionable HISQ (Staggered! Fourth root?) and

  Domain Wall (5^{th} Dimensions shorter than Space?)

  Will prevail in the computations of mesons and baryons
- and depending on how you trust calculations from one or two groups

  Obelix may find himself alone on the arena of 2015.