



Lattice vs Experiment

road to success / road ahead

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de l'Univers





Lattice vs. Experiment road to success / road ahead

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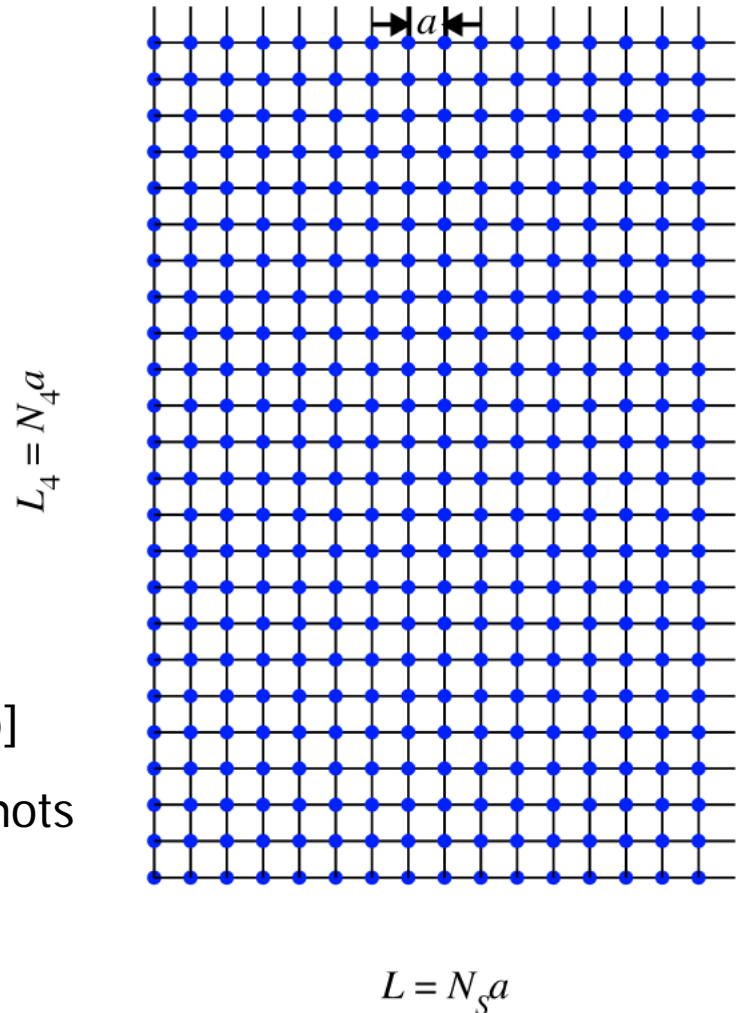
Brief History of Euclidian Time

- 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

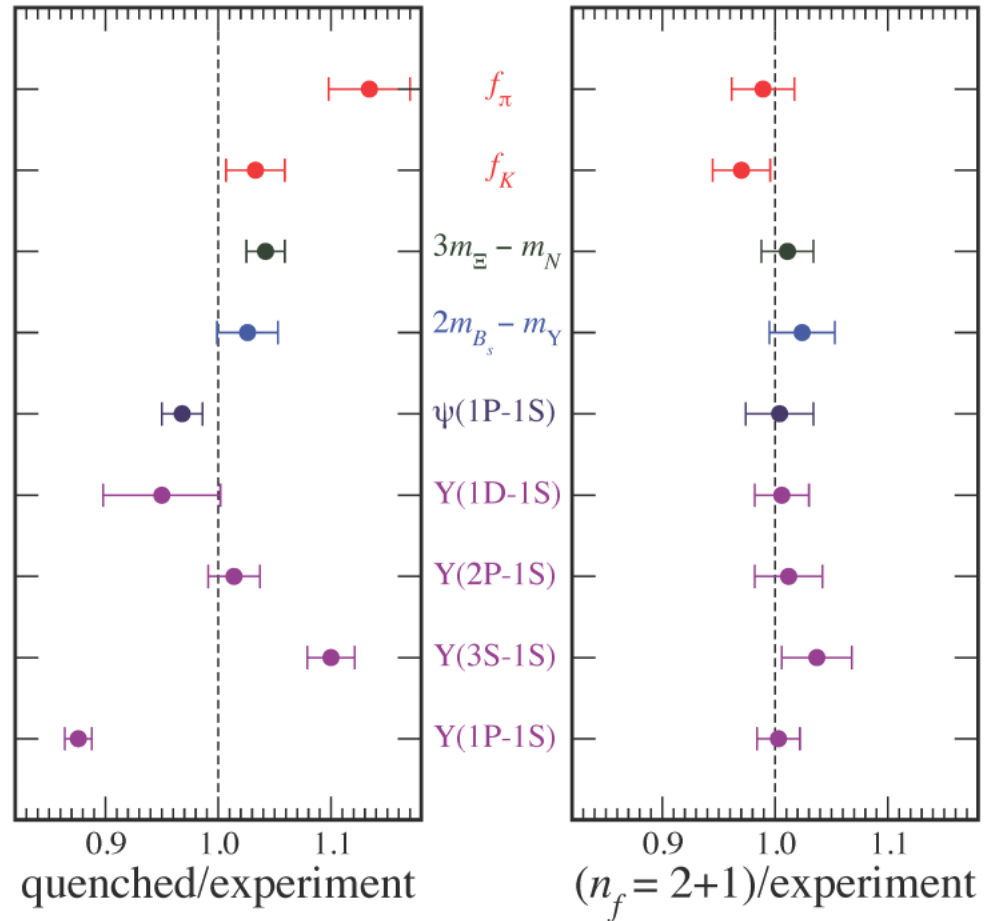
$$\begin{aligned}\langle \bullet \rangle &= \frac{1}{Z} \int \mathcal{D}U \mathcal{D}\psi \mathcal{D}\bar{\psi} \exp(-S) [\bullet] \\ &= \frac{1}{Z} \int \mathcal{D}U \det(\not{D} + m) \exp(-S) [\bullet']\end{aligned}$$

- 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

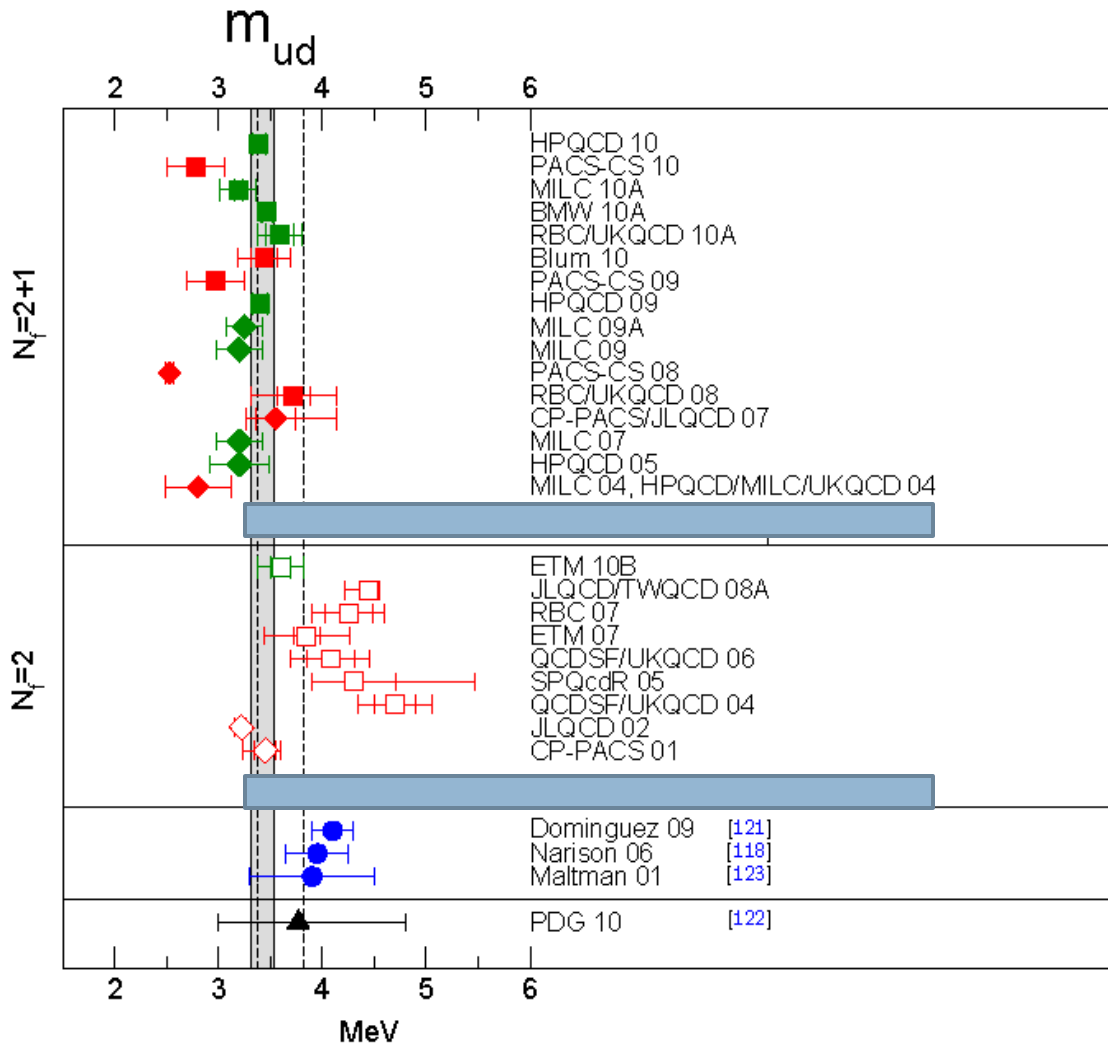


Brief History of Euclidian Time

- 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

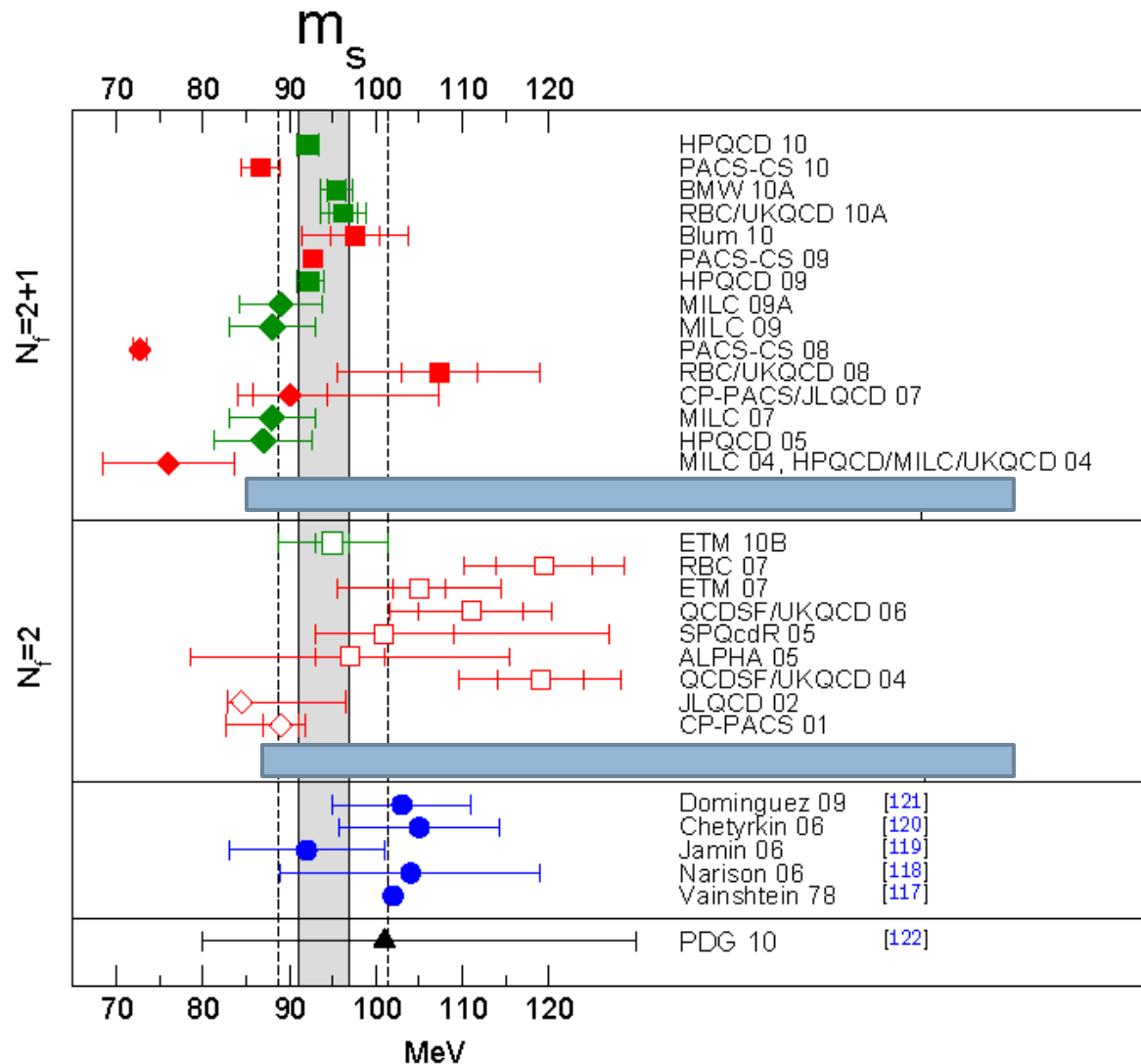


Sweet smell of success



- 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

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

$$V_{ud} / V_{us} \quad \text{from} \quad K \rightarrow l\mu / \pi \rightarrow l\mu$$

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

$$V_{us} \quad \text{from} \quad K \rightarrow \pi l$$

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

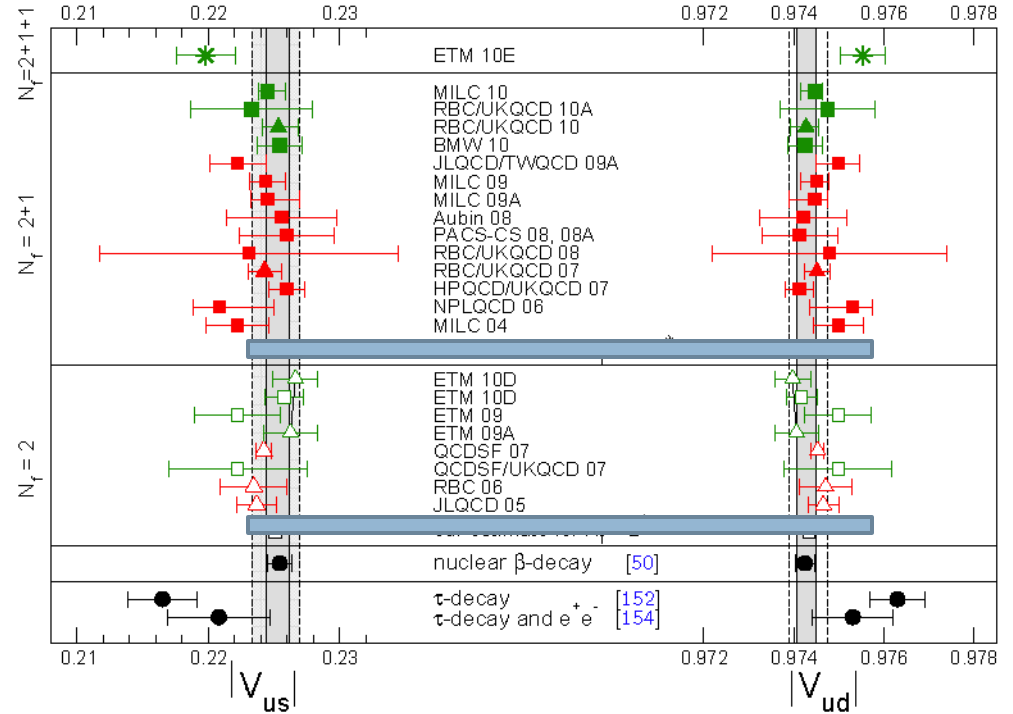
The Battle for Unitarity

the first row

V_{ud}	V_{us}	V_{ub}
V_{cd}	V_{cs}	V_{cb}
V_{td}	V_{ts}	V_{tb}

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

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



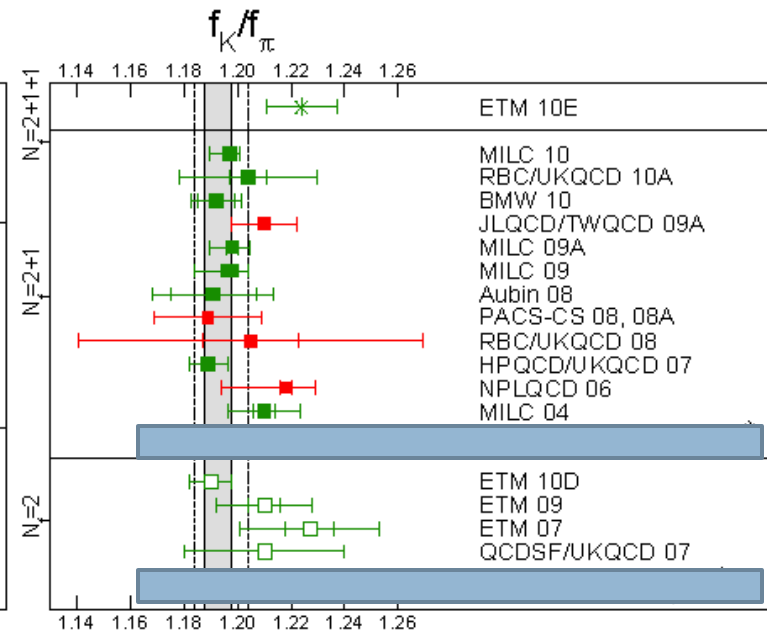
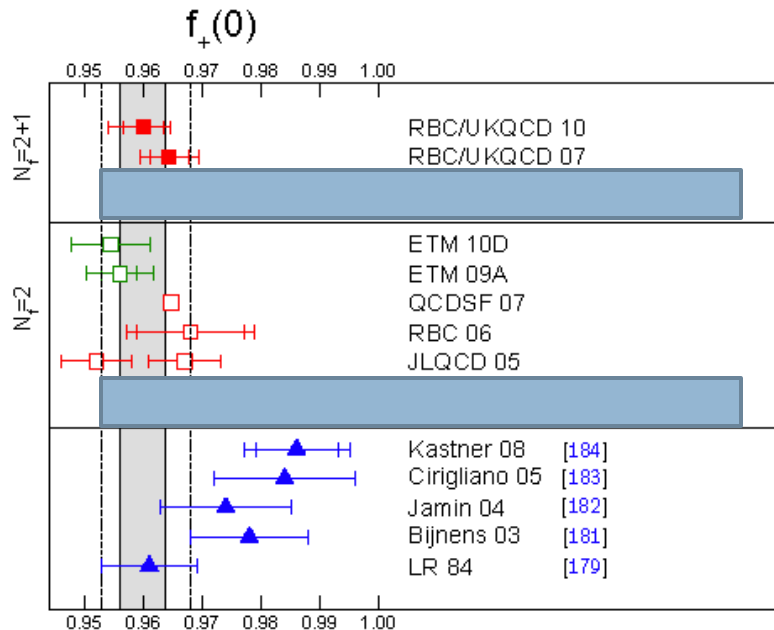
The Battle for Unitarity

the first row

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

$$|f_+(0)| = 0.96(1)$$

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

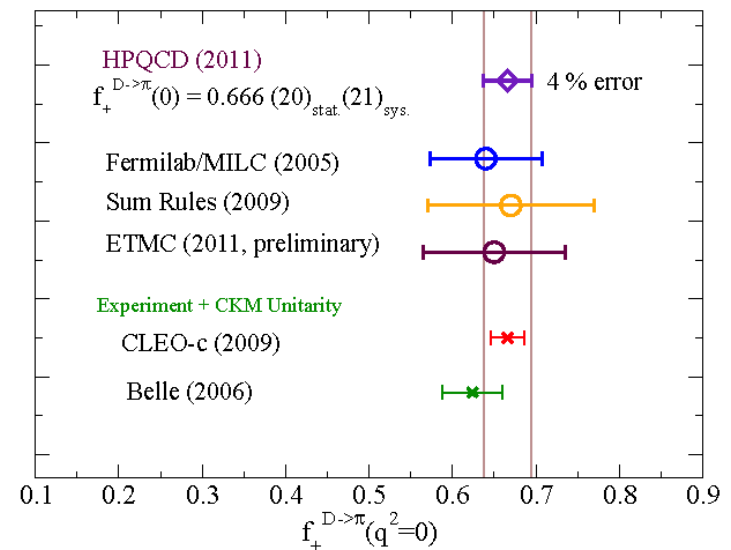
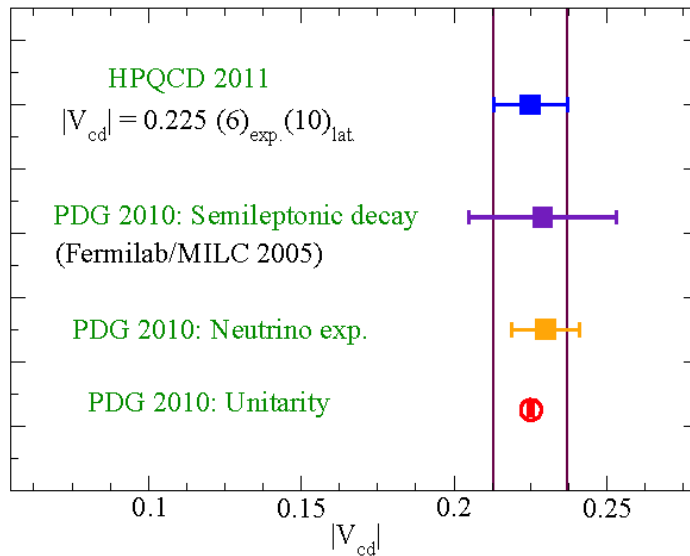


The Battle for Unitarity

second row

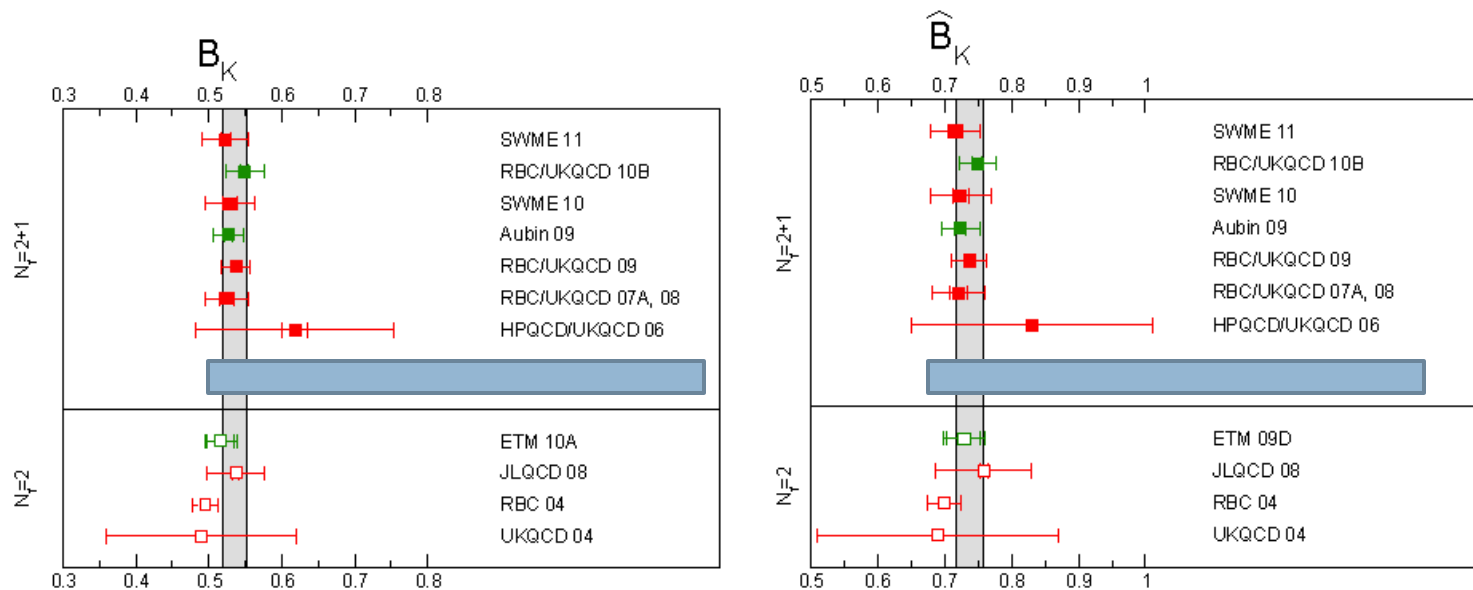
$$\begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix}$$

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



Heavy Weighters challenges of B-physics

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



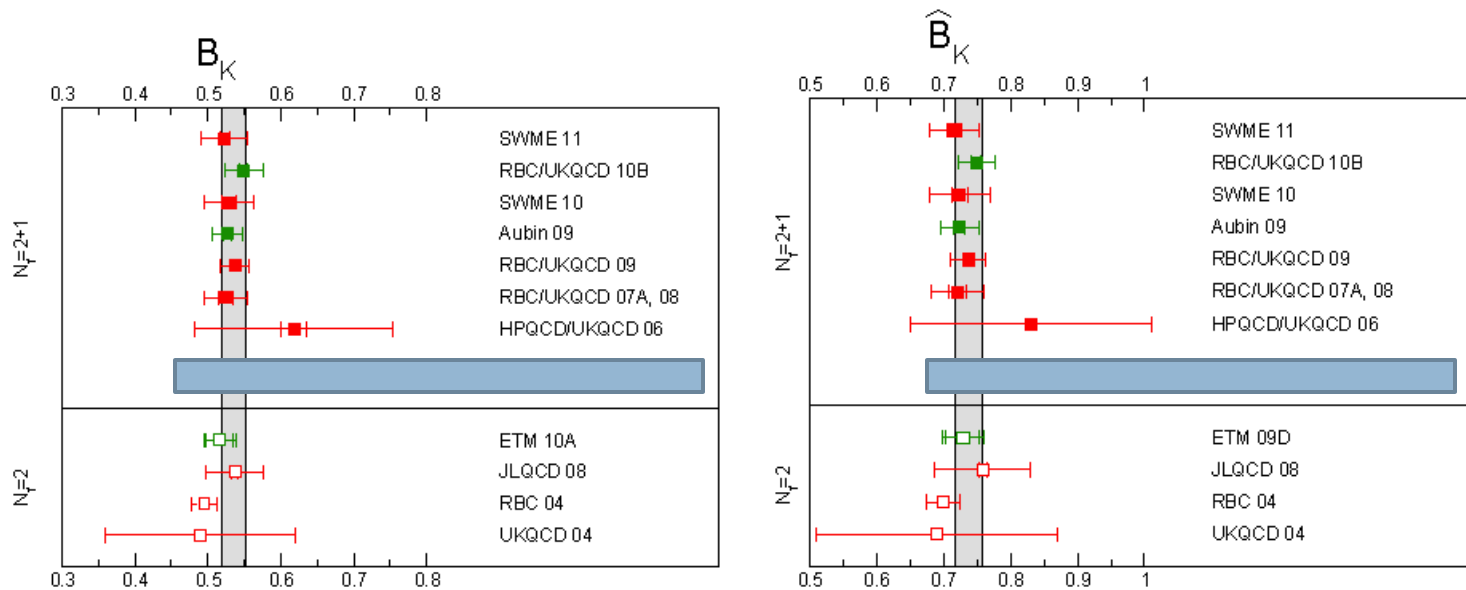
Heavy Weighters

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

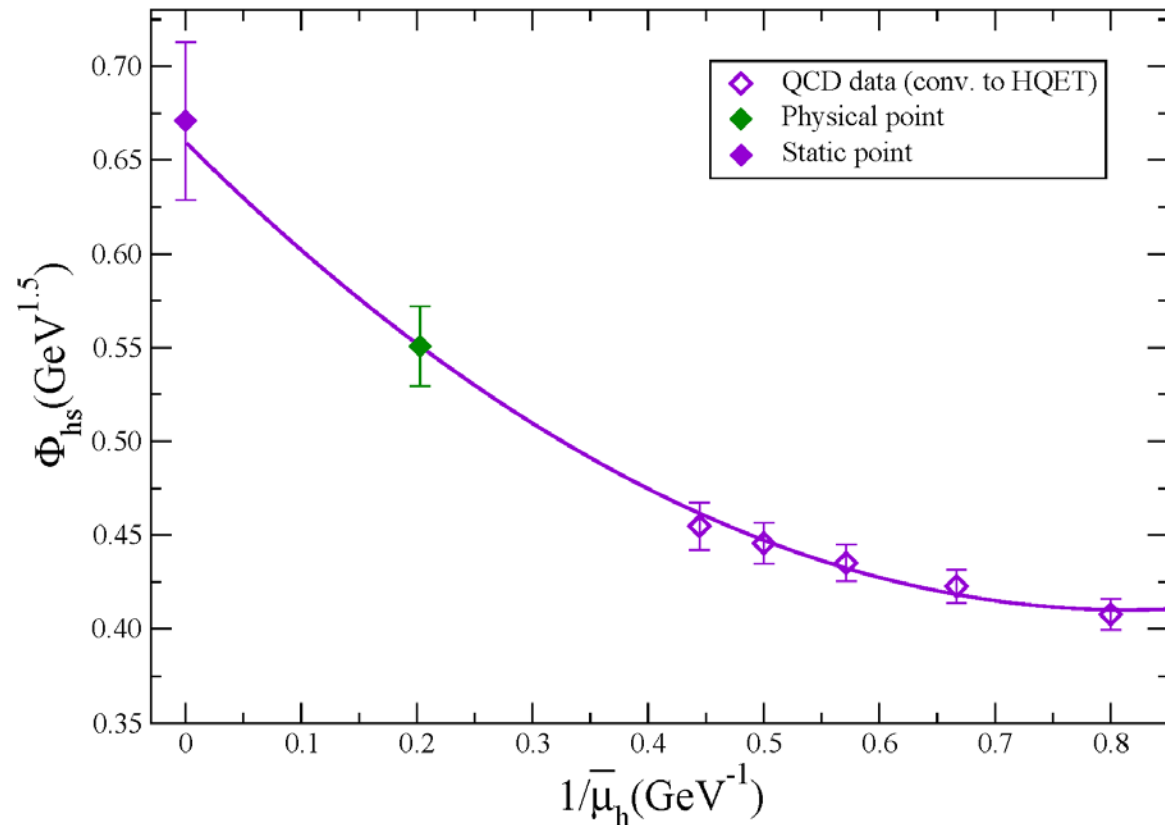
- The problem with HQET, Fermilab, NRQCD etc
- is that they are not controllable approximations
- we can neither predict the systematic error from them
- nor gradually improve them

- 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)



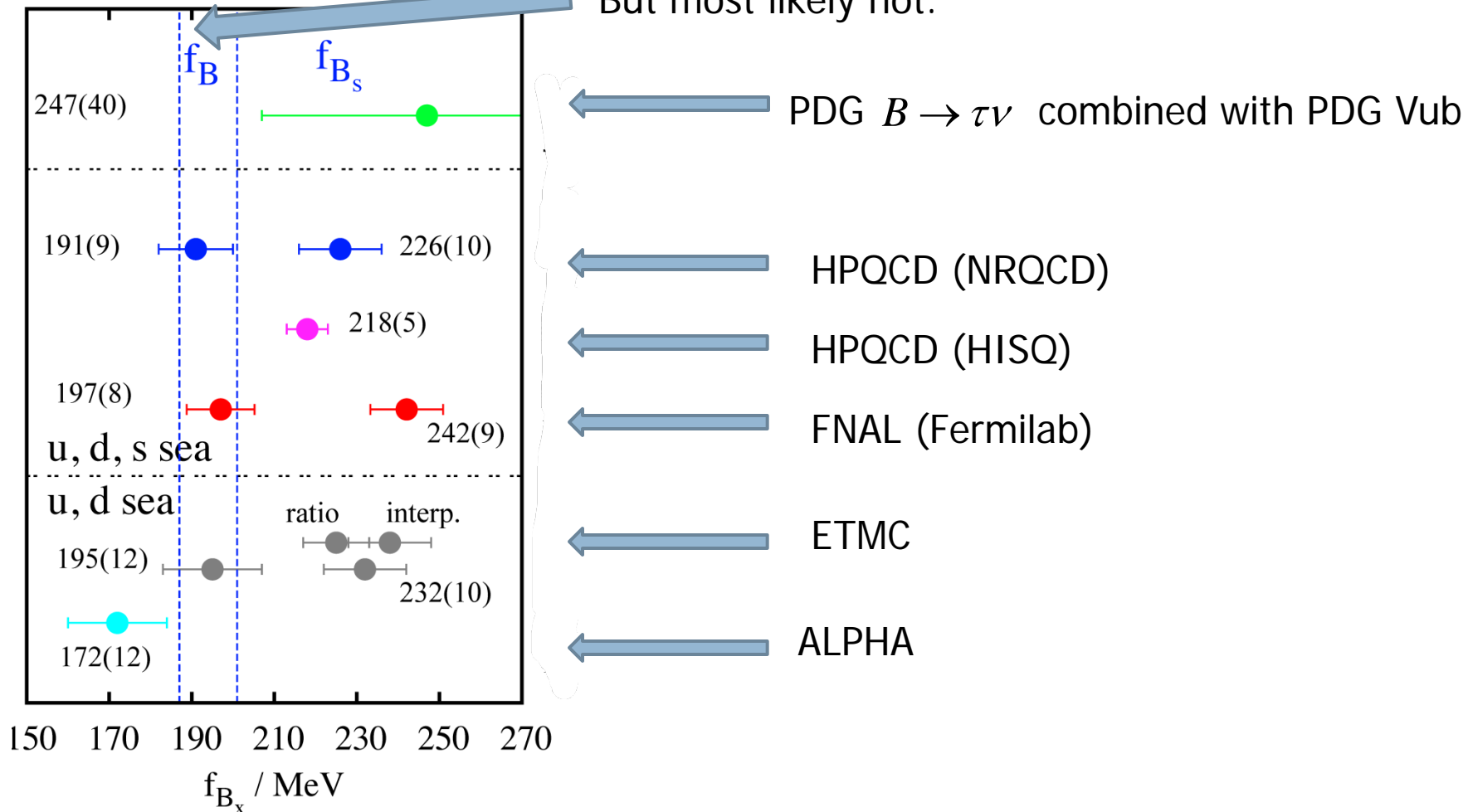
Apples and Oranges

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

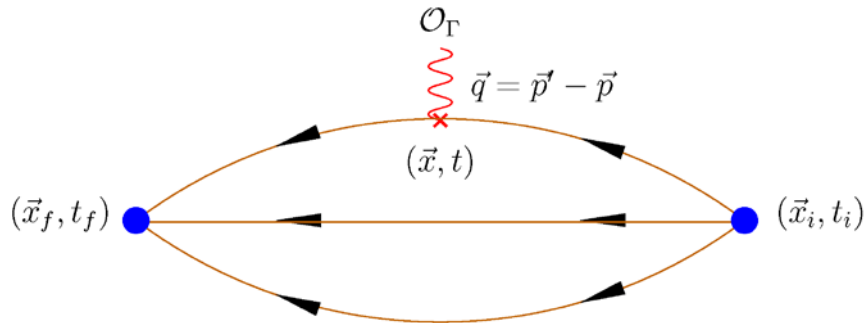
Heavy Weighters challenges of B-physics

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

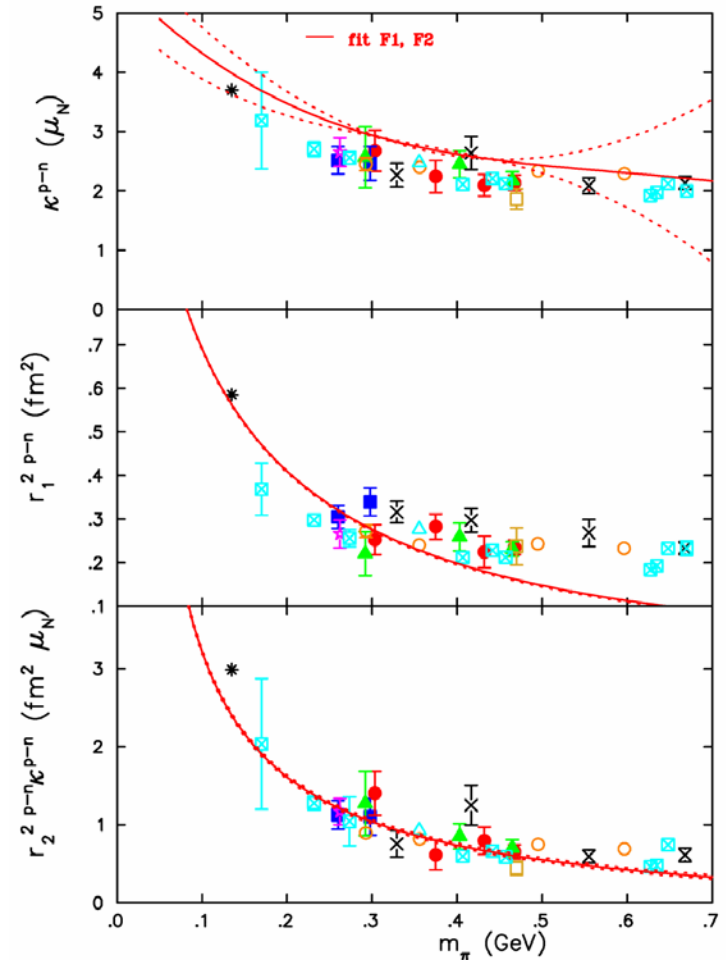


Triplets from Protonville

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 light quark mass

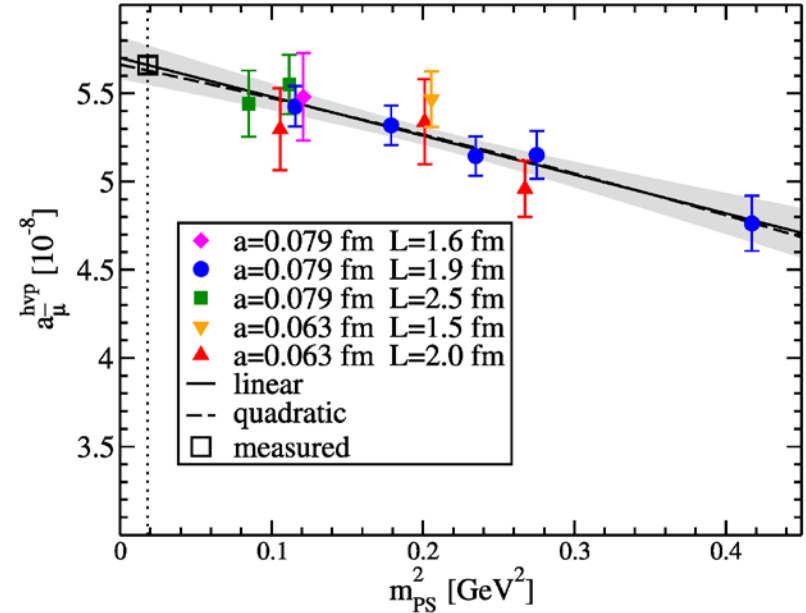


Searching for New Physics

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

Strong Coupling Constant $\alpha_{\overline{MS}}(M_Z^2)$

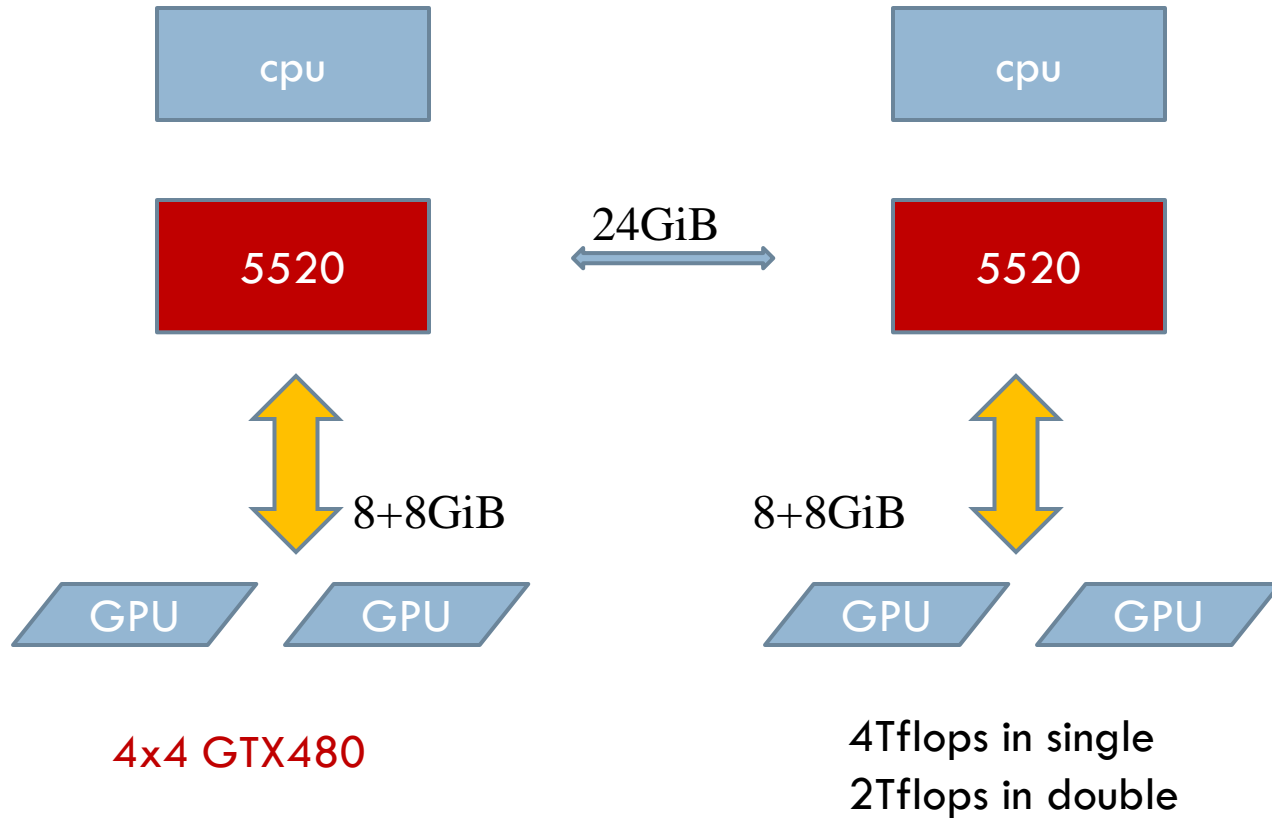
group	value	comment
LPT-IRFU-Grenoble-Spain (ETMC)	0.1200(14)	This is us. With dynamic strange and charm.
World Average Lattice	0.1184(7)	We are more than one sigma away! Problem?
But no, it is dominated by HPQCD	0.1183(8)	We find their error heavily underestimated
New PACS-CS result from Japan	0.1205(8)(5)	Not staggered, with dynamic strange
World average w/out HPQCD but with PACS-CS	0.1190(9)	
ALEPH	0.1224(39)	Dominated by perturbative error from QCD
Hadronic Tau-decays	0.1197(16)	Davier et al

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?

FermiLake Cluster @CEA

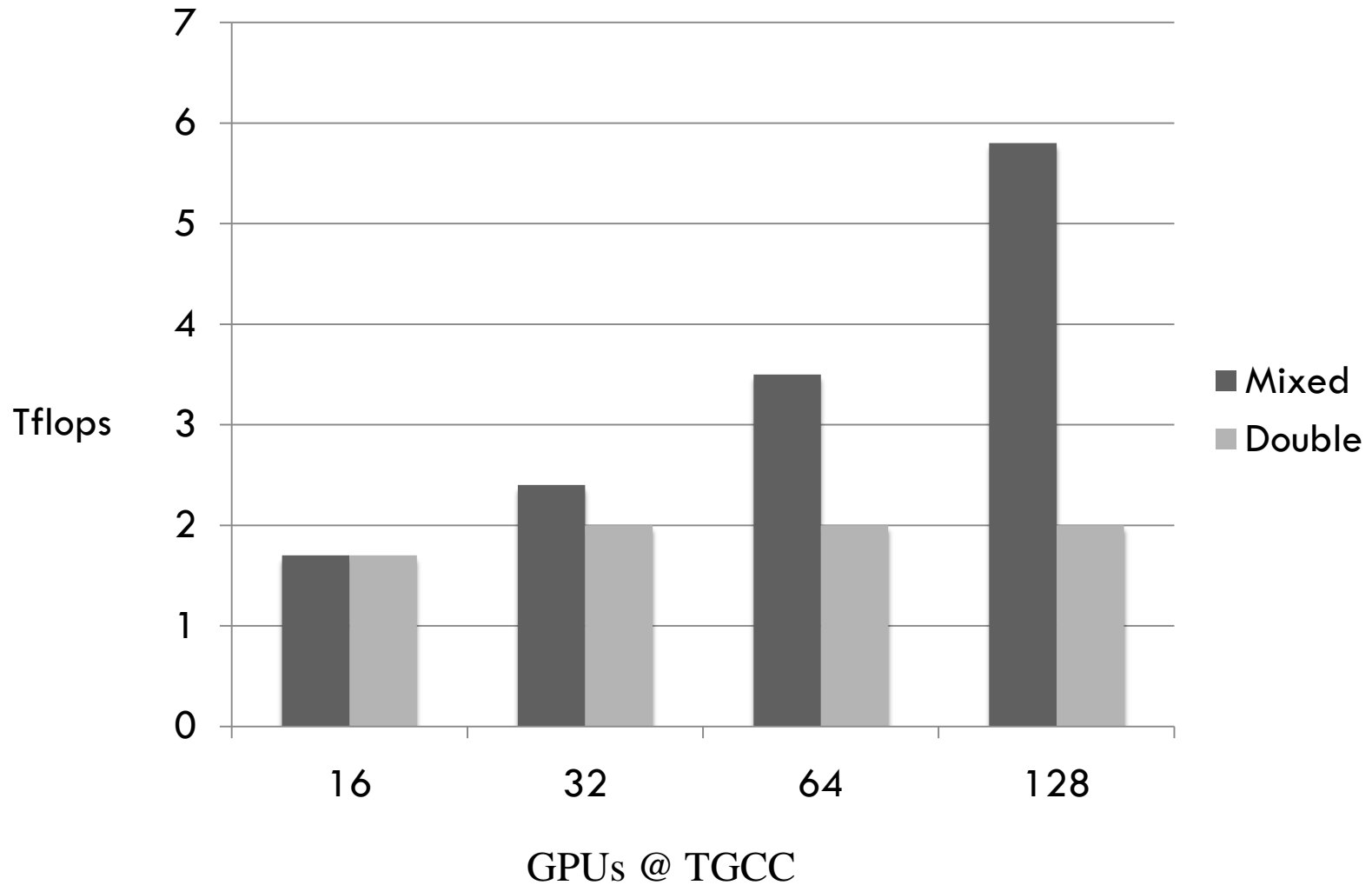


ONE-TWO RACKS of BlueGene or 36million core-hours/year!
... for 25k hardware+3k Electricity
...but for 16 distinct jobs

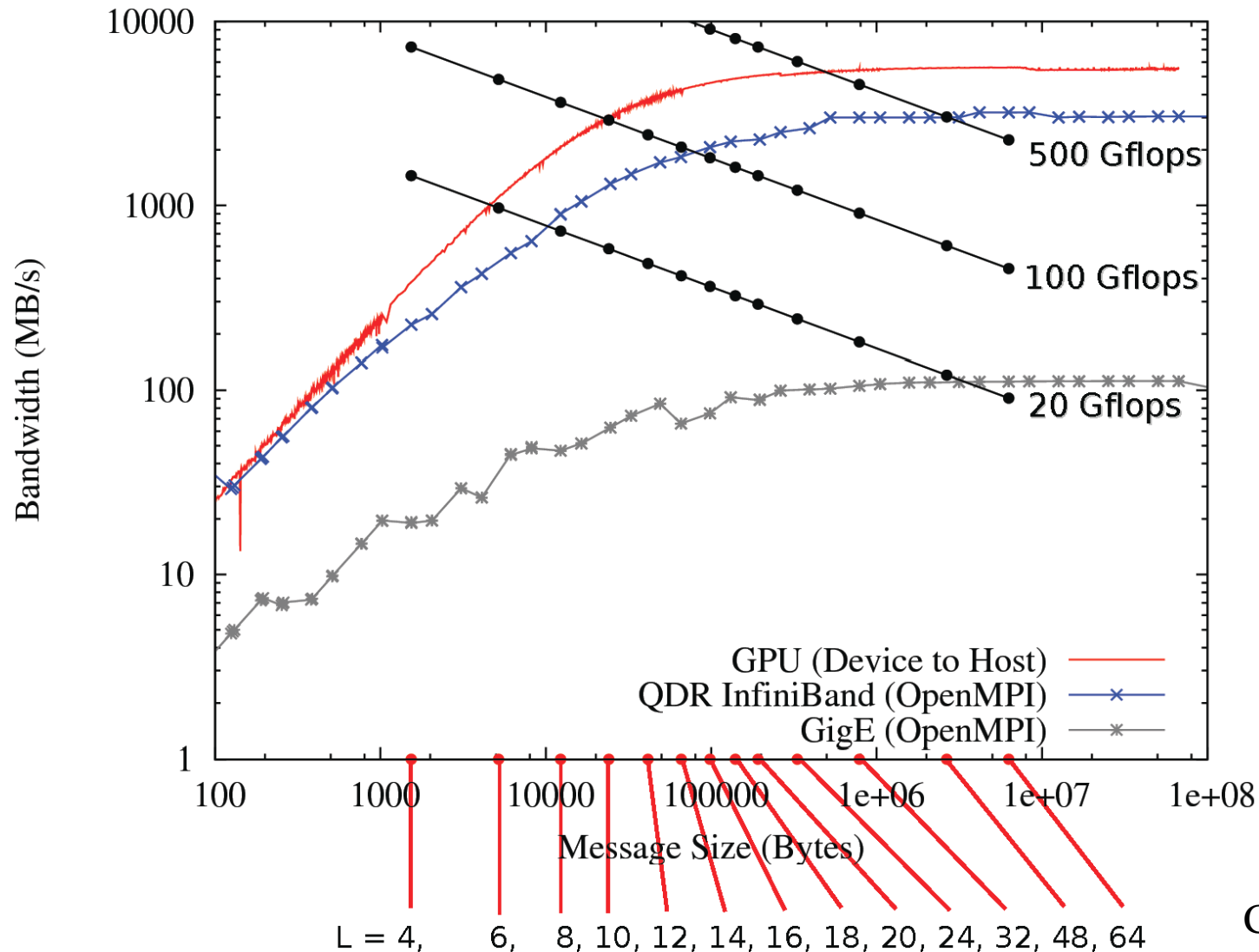
It takes two to Tango

- 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

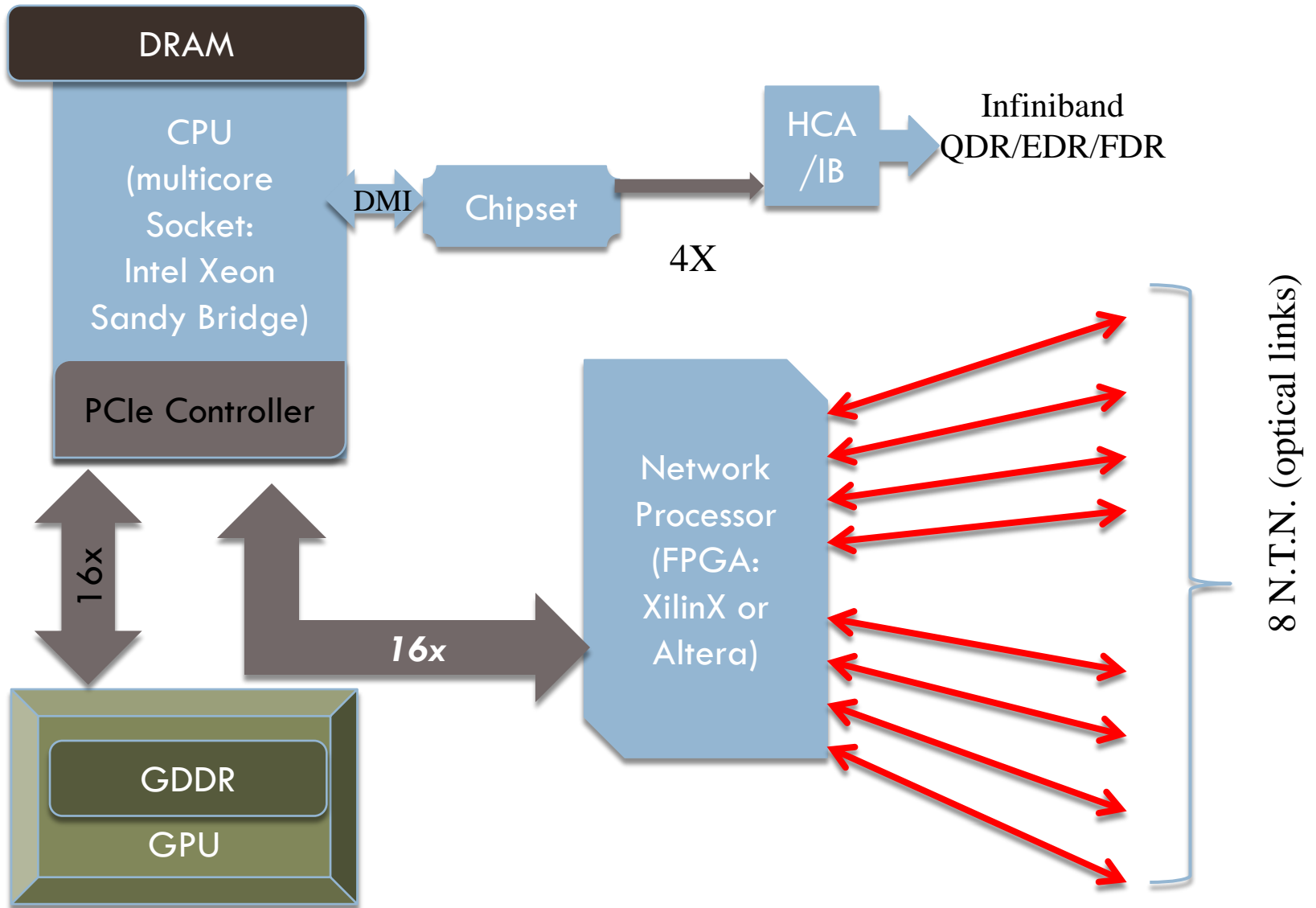
State of Things: Scaling of the Inverter



Modelling MultiGPU Performance



Project: NEPAL



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 Edinburgh, 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-fat is pointless, Curie-Hybride is not so bad
Exascaland	\$68m from Congress for R&D, \$21m for DataIntensiveSciences

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 MetaIX (formerly known as PetaQCD)
- which wants to make PhD students to do physics,
and not assembly programming
- ANR project deposed yesterday.

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

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

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

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

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

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

High Level Description

$$U(-d1, s1) = U(d1, s1 - d1)^\dagger$$

$$\text{Preconditioner1}(\text{Dirac}) = Pe$$

$$\text{Preconditioner2}(\text{Dirac}) = Po$$

$$\gamma(d1)^\dagger = -\gamma(d1)$$

$$\sigma(-d1) = -\sigma(d1)$$

$$g_a(d1) = i * \gamma_5 * \gamma(d1)$$

$$\text{invertible}(I_S + c * \gamma_5) = \text{true}$$

$$\text{invertible}(I_S - c * \gamma_5) = \text{true}$$

$$\text{type}(\gamma(d1)) = S \times S$$

$$\text{type}(\sigma(d1)) = \text{Half}S \times \text{Half}S$$

$$\text{type}(U(d1, s1)) = C \times C$$

$$\text{type}(\gamma_5) = S \times S$$

$$\gamma_5^\dagger = \gamma_5$$

$$D = \{dx, dy, dz, dt\}$$

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

Output : $x \in V$

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

Require : $A^\dagger = A$

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

Algorithm:

$r = b ;$

$p = r ;$

$n_r = (r | r) ;$

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

$Ap = A * p ;$

$n_r = (r | r) ;$

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

$x = x + \alpha * p ;$

$r = r - \alpha * Ap ;$

$n_{r1} = (r | r) ;$

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

$p = r + \beta * p ;$

$n_r = n_{r1} ;$

**Conjugate
Gradient**

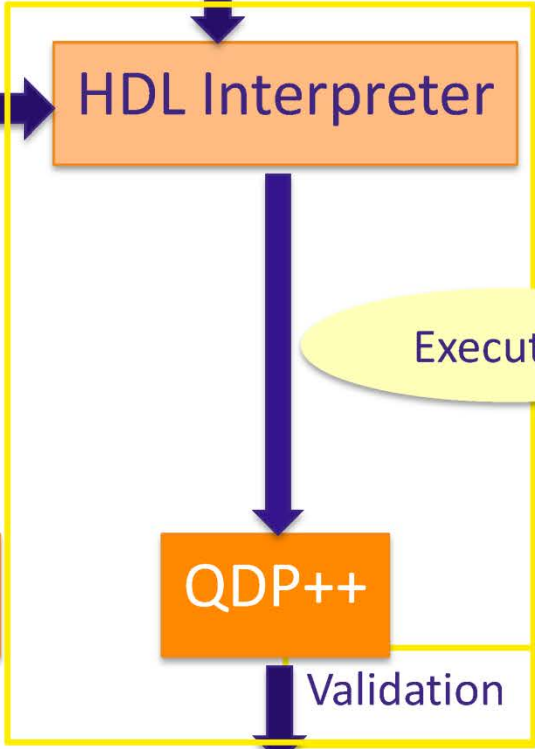
High Level Abstraction for Inversion of Dirac Operator

Compilation on the fly

HDL Abstract Computation Tree Generation



HDL Parallelization Engine



HDL Interpreter

Execution

Hybrid implementation

Generation

MPI Node Code

QUDA GPU code

QDP++

Compilation & execution

Validation

Hybrid Architecture

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 SPhN/LPT/Orsay) Using hardware at CEA/IRFU

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 (5th 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.