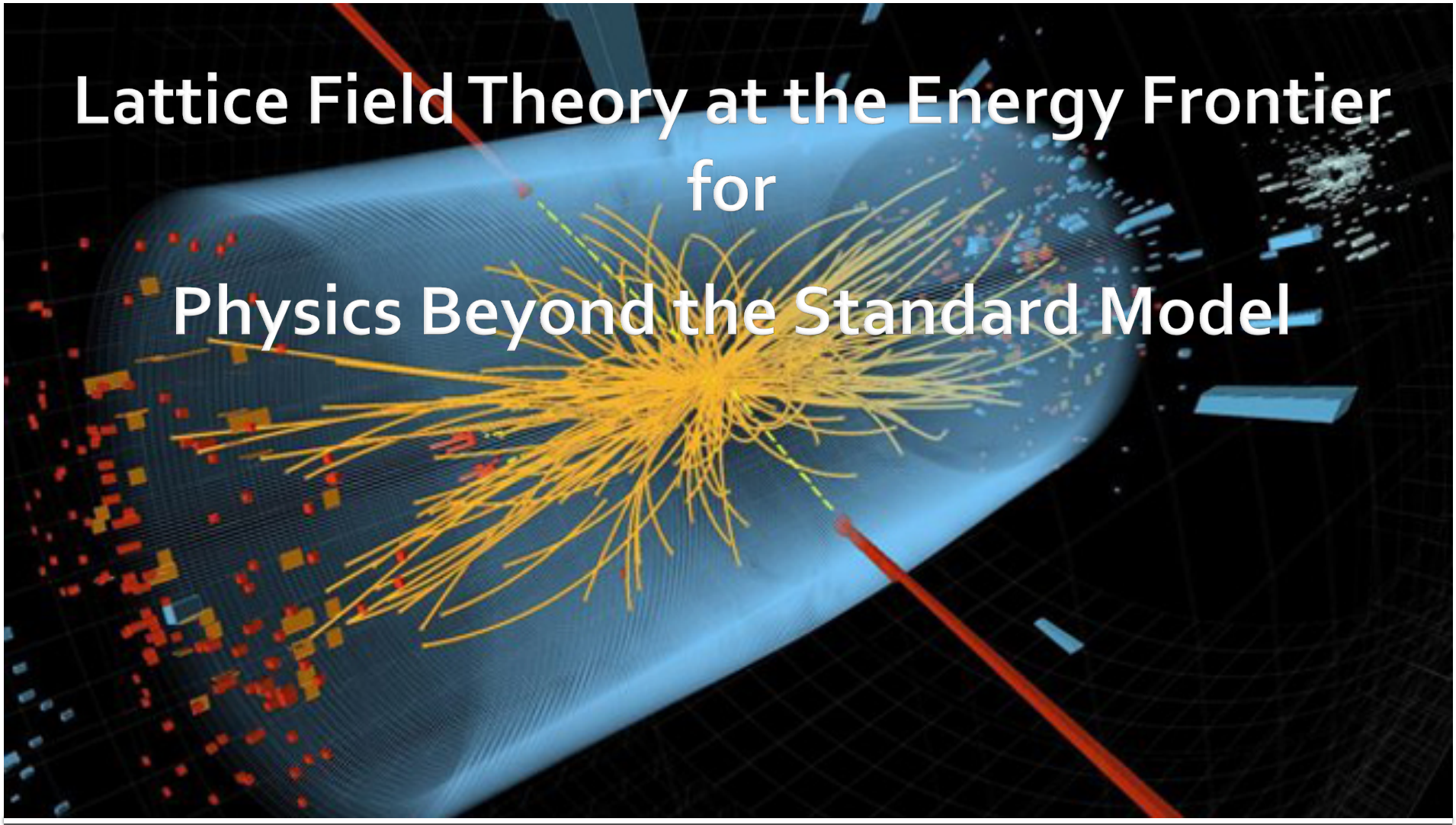


Lattice Field Theory at the Energy Frontier for Physics Beyond the Standard Model

Rich Brower Boston University
SciDAC Software Co-ordinator for USQCD

NERSC HEP Requirements Review
Rockville, MD November 27-18, 2012

Introduction

- There is general agreement that the Standard Model is likely to be a low energy approximation to new (strong) dynamics.
- But experiment* has yet to give substantial clues to guide theorist and there are a huge number of possible extensions to the the Standard Model.
- Still Lattice Field Theory does provide a powerful approach to investigate new strong dynamics as proven for QCD.

* Except of course DARK MATTER & Gravity!

Challenges for BSM Lattice Field Theory

I. Rapid response to New Actions

- (to replace elementary Higgs?)

II. Rapid response to New Algorithms

- (vast increase in multiple scales)

III. Rapid response to New Architectures

- (Increasingly hierarchical and heterogeneous)

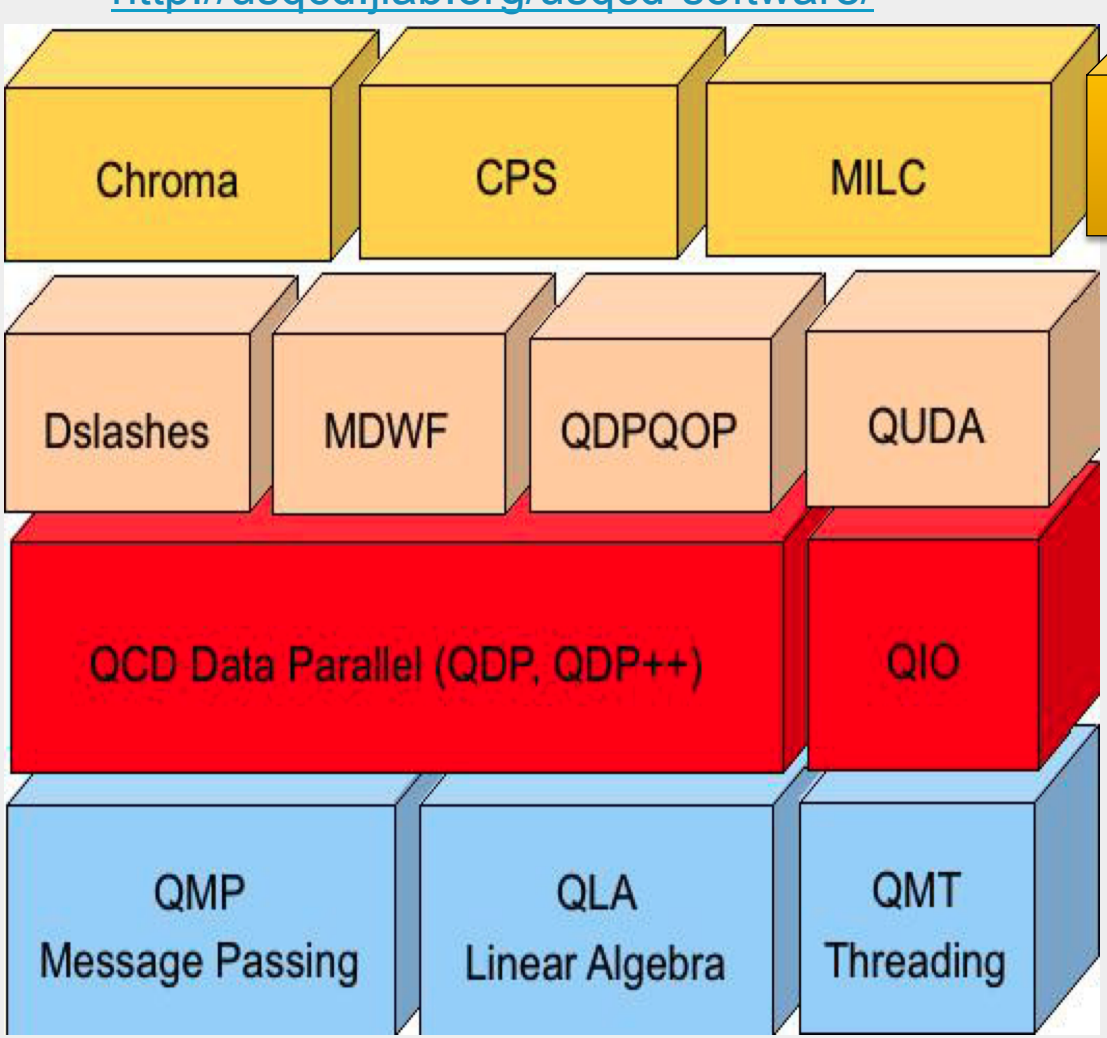
Conclusions!

- Lattice Field Theory at Energy Frontier has great promise, maybe essential BUT….
  - Software must be Agile: New theories & Algorithms & Arch.
  - Interaction with Experimentalists & Phenomenologists(*)
  - To move quickly to most promising theories!

***See Lattice Meets Experiment 2012: Beyond the Standard Model 26—27 October 2012**
http://www-hep.colorado.edu/~schaich/lat-exp-2012/

SciDAC LGT Software Stack helps (supports a "Team of Rivals")

http://usqcd.jlab.org/usqcd-software/



856 files

CPS = 1749 files

MILC = 2300 files

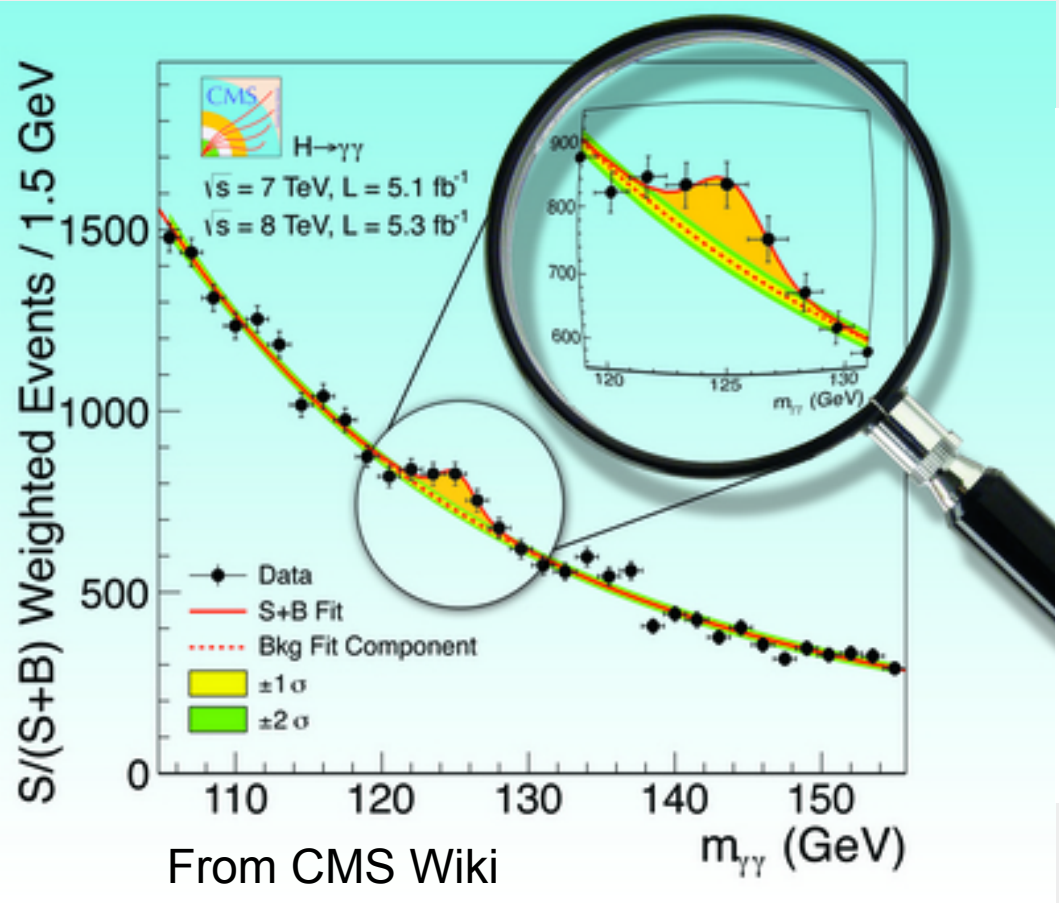
Algorithms

QLA/perl = 23000 files

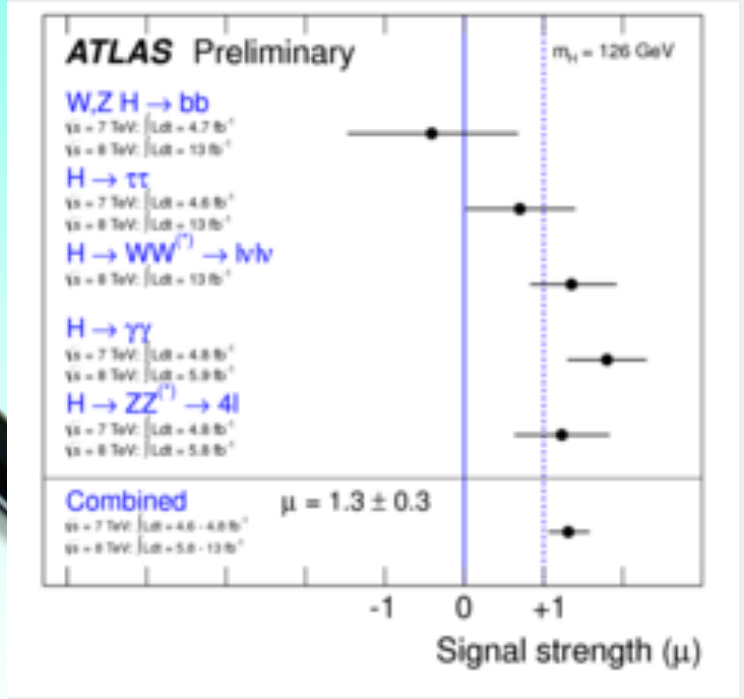
QUDA/python = 221 files

Architecture

July 4th: LHC Result: There is a light scalar --- apparently a Higgs – hopefully "composite" !

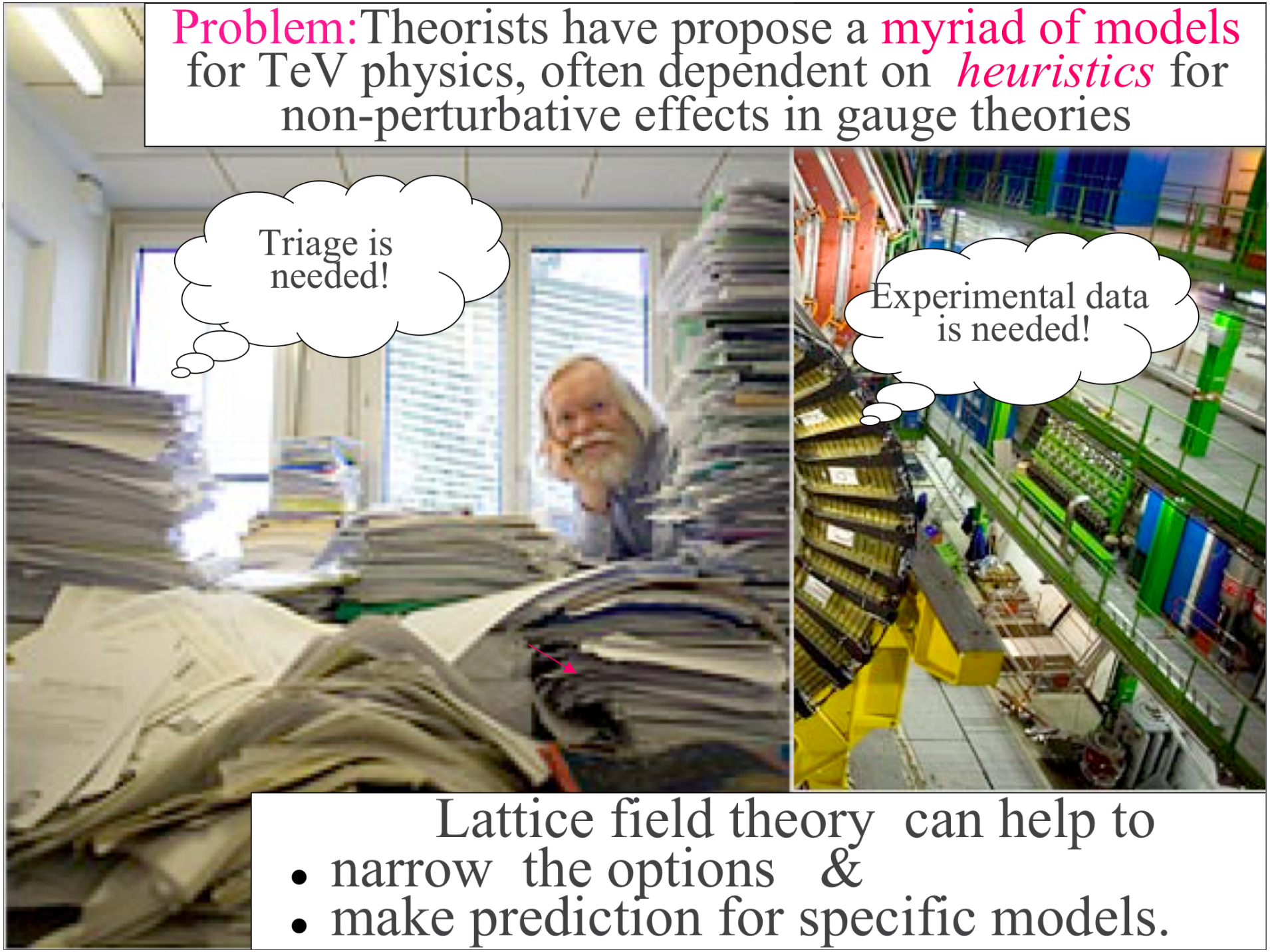


From CMS Wiki



Understanding the "Higgs" and extensions to Standard Model requires all "hands on deck": Experiment/Models/Lattice Field Theory. It is difficult as is!

Problem: Theorists have propose a myriad of models for TeV physics, often dependent on *heuristics* for non-perturbative effects in gauge theories



Lattice field theory can help to

- narrow the options &
- make prediction for specific models.

Since 2007
Lattice Strong Dynamics (LSD) collaboration has begun to explore BSM electro-weak physics

Heechang Na
James Osborn

Rich Brower
Michael Cheng
Meifeng Lin
Claudio Rebbi
Oliver Witzel

Ethan Neil

Sergey Syritsyn

Michael Buchoff
Chris Schroeder
Pavlos Vranas

Ron Babich
Mike Clark

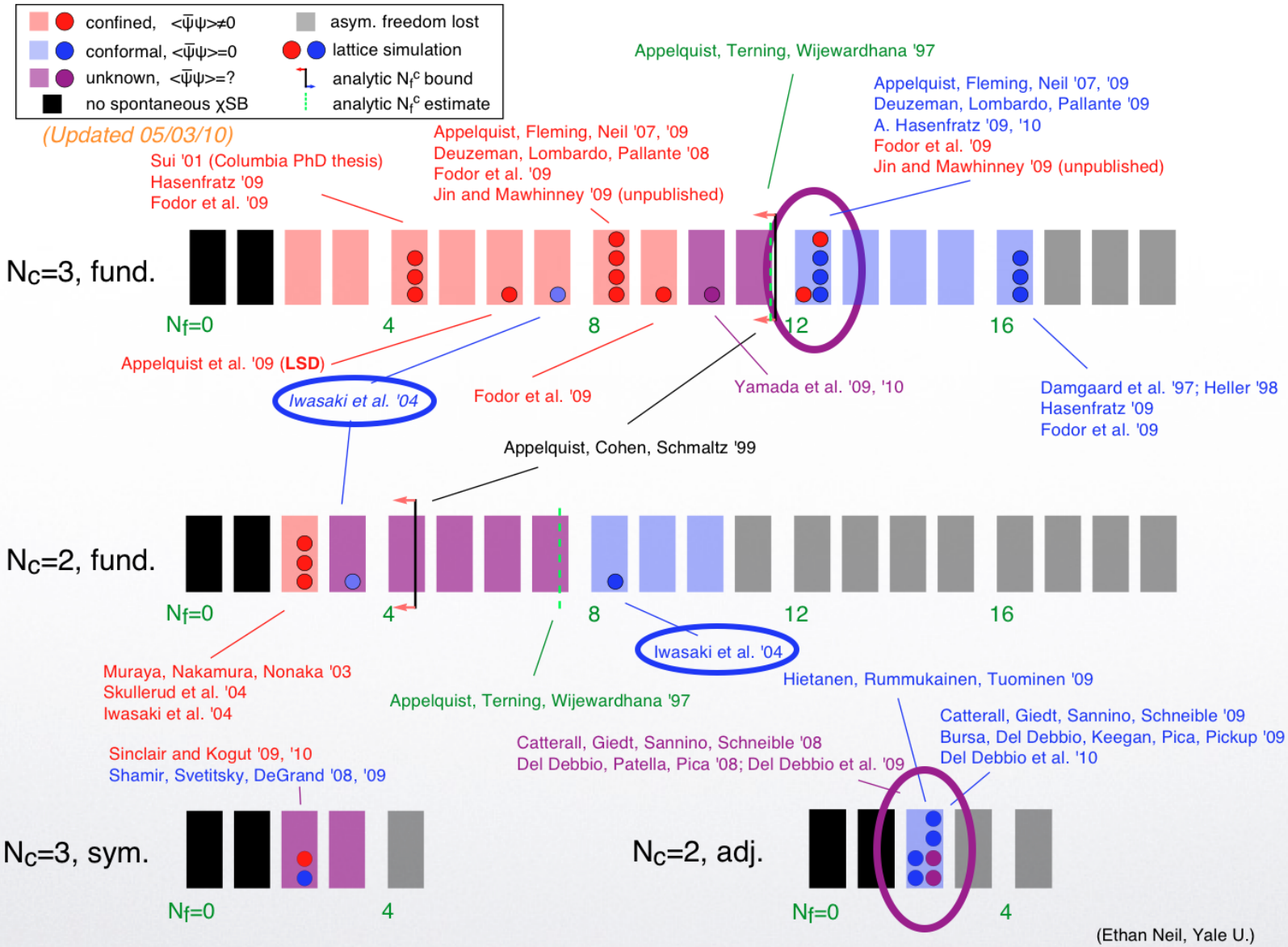
Joe Kiskis

David Schaich

Saul Cohen

Tom Appelquist
George Fleming
Gennady Voronov

After Hiatus, Searching in Earnest



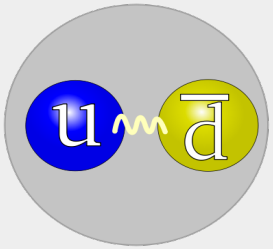
(Ethan Neil, Yale U.)

"Technicolor" aka TeV scale strong dynamics

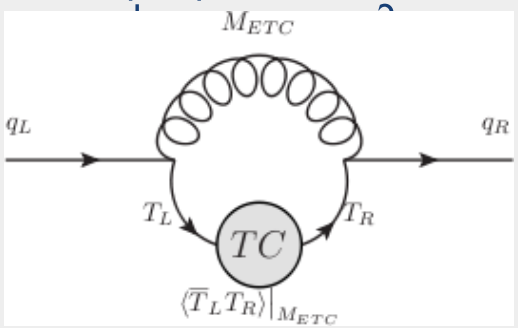
- The techni-pions are eaten by W+, Z, W but will the structure violate the S-parameter precision test?

  S = < > O(0.1)

- Extended Technicolor: Can we build in flavor physics with very small FCNC and large enough



$$\frac{\langle \overline{Q}Q \rangle}{F^3_{\pi_T}} \gg \frac{\langle \overline{q}q \rangle}{f^3_\pi}$$

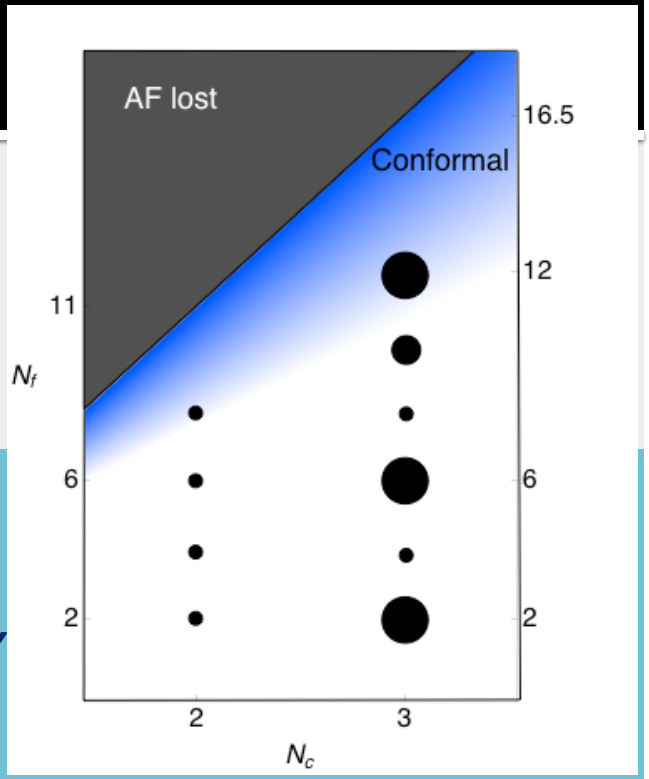


Techni-quark Tev Scale

QCD Gev scale

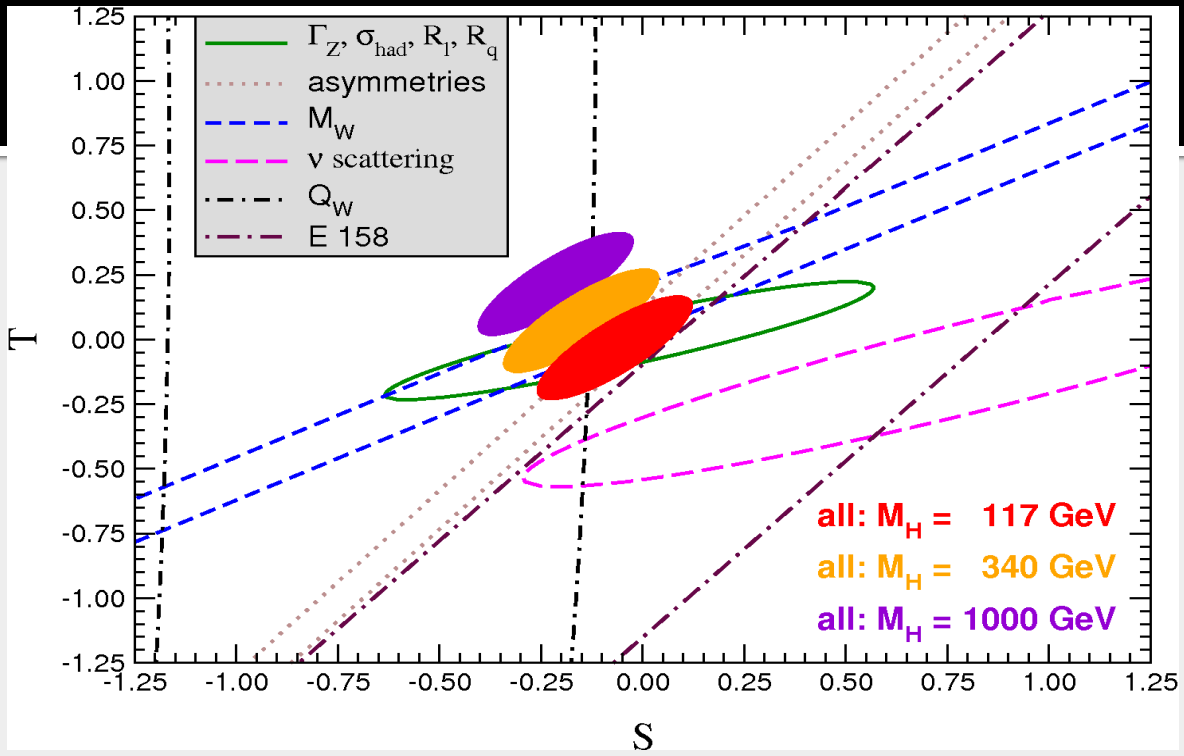
Some USQCD BSM projects

SU(3) with N_f=2,6, 8, 10.Domain Wall code on BlueGene & QCD experience.
SU(2) code ready, optimization ongoing.



- Higgs-Like Mechanism
  - Dilaton imposter & Conformality/SUSY
  - Composite Pseudo BG Higgs
- Phenomenology:
  - *S* parameter, condensate enhancement/mass anomalous dimension.
  - *WW* scattering, dark matter form factors.

S-parameter Precision EW constraint



Peskin& Takeuchi: Is "technicolor" S parameter too large ?

$$S = 4\pi(m_{a1}^2 - m_\rho^2)(1/m_\rho^2 + 1/m_{a1}^2)F_\rho F_{a1}$$
$$= 0.25\frac{N_f}{2}\frac{N_c}{3}$$

resonance saturation

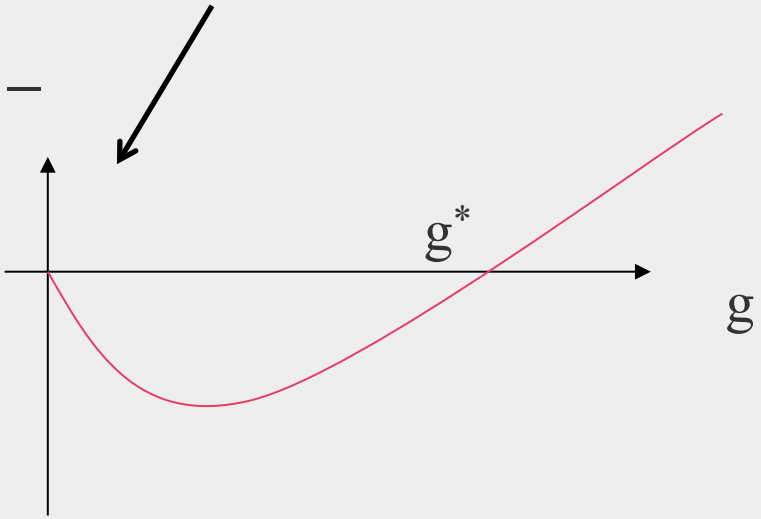
chiral pert. th.

$$S = \frac{1}{48\pi}(N_f^2 - 4)\log\left[\frac{M_\rho^2}{M_{PNGB}^2}\right]$$

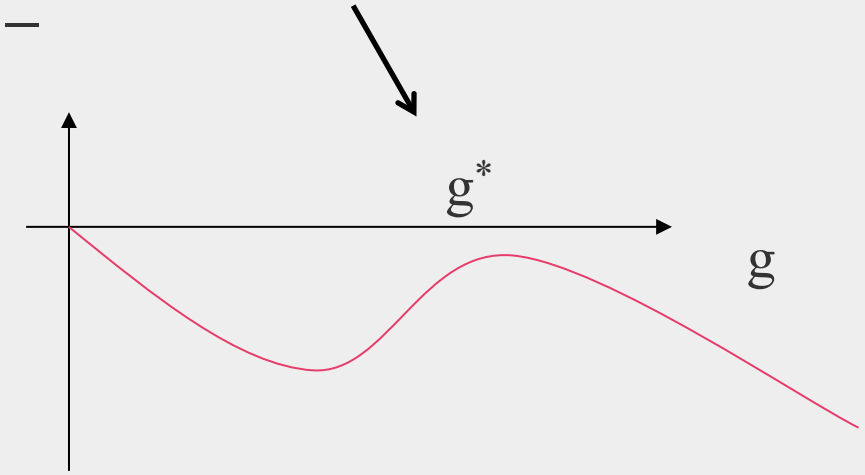
- An IR fixed point can emerge already in the two-loop β function as you increase the number N_f of fermions.

$$\beta(g) = b_0 g^3 + b_1 g^5 + \cdots$$

$b_0 < 0$ for $N_f < 11N_c/2 = 16.5$



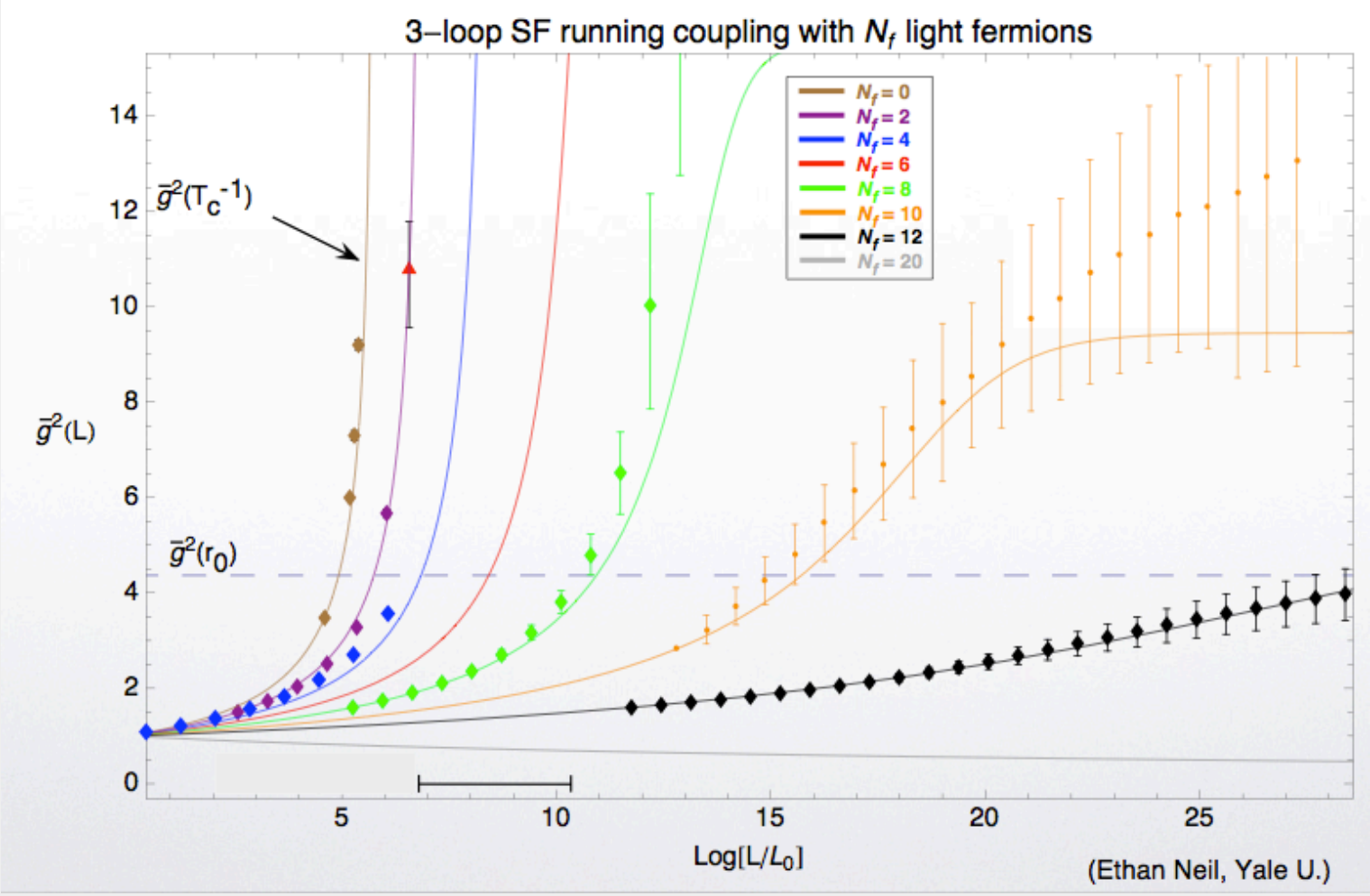
$b_1 > 0$ for $N_f > 153/14$



- Conformal Window: 16.5> N_f > N^*_f

⊡Walking: N_f < N^*_f , but close to N^*_f

Impact of increasing Fermion flavors.



- Lattice calculations confirm the general picture (details still hotly debated).

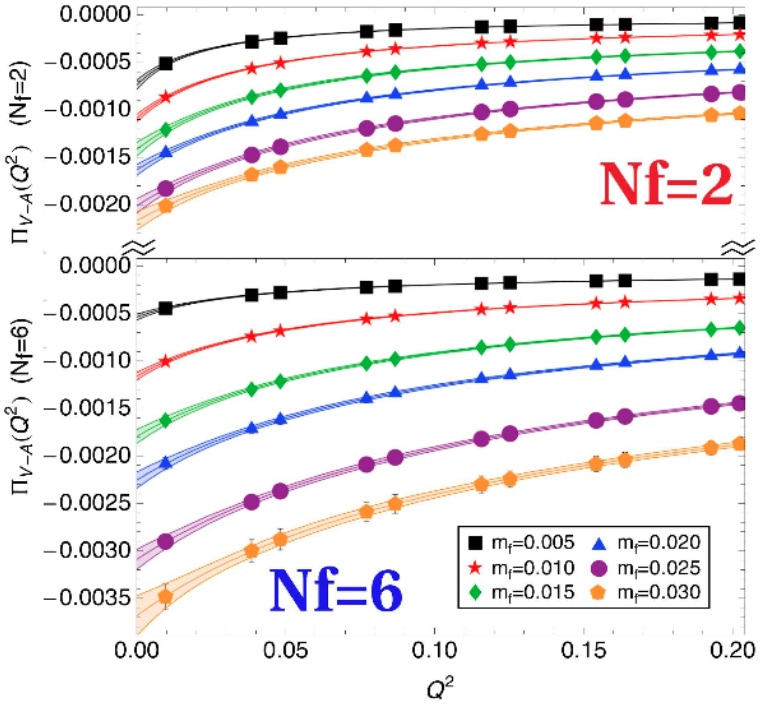
S parameter

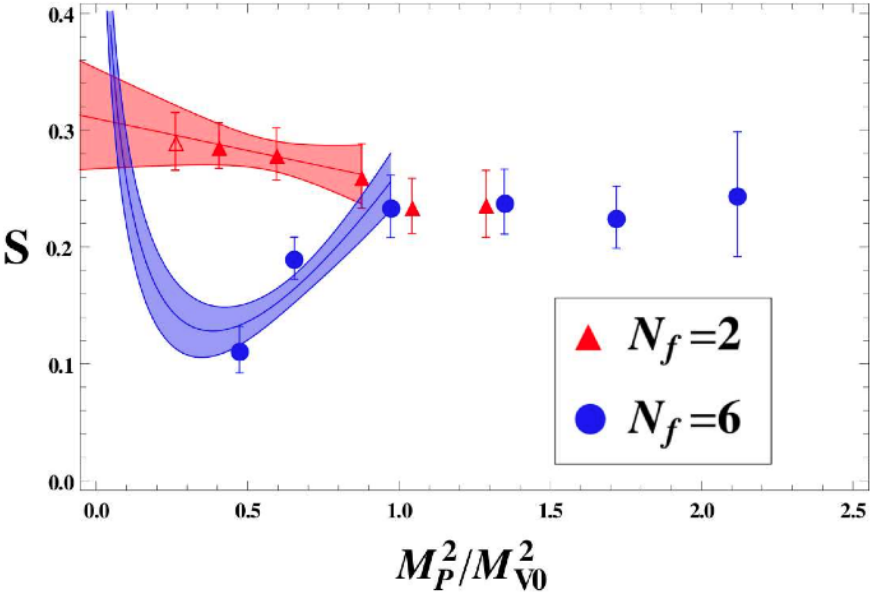
LSD Collaboration, PRL 106:231601 (2011)

Constraint from vacuum polarizations $\Pi^{\mu\nu}(Q)$ of EW gauge bosons

$$S = 4\pi N_D \lim_{Q^2 \to 0} \frac{d}{dQ^2} \Pi_{V-A}(Q^2) - \Delta S_{SM}$$

$\Pi_{V-A}(Q^2)$

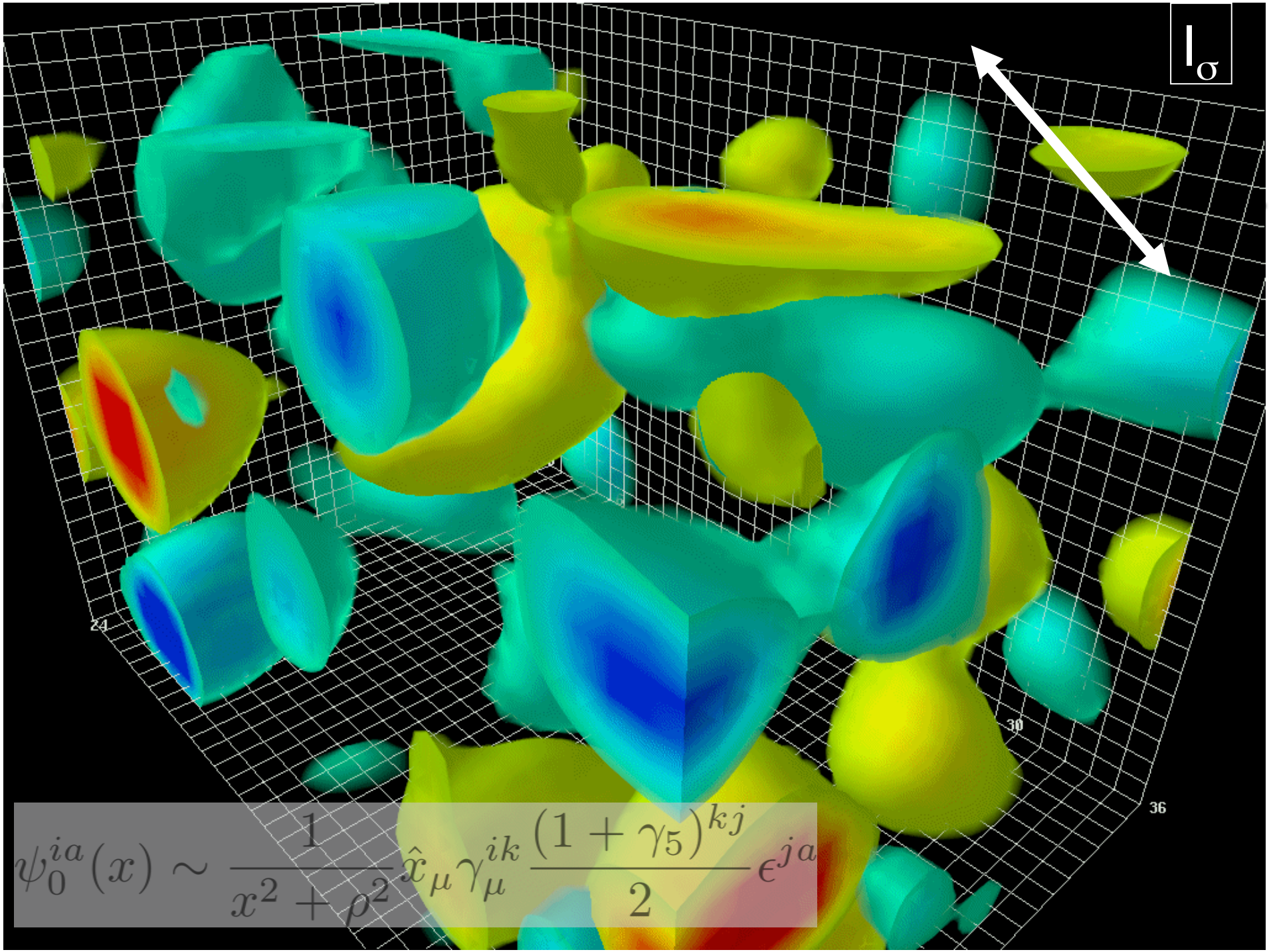




(Linear+chiral log fits to guide the eye)

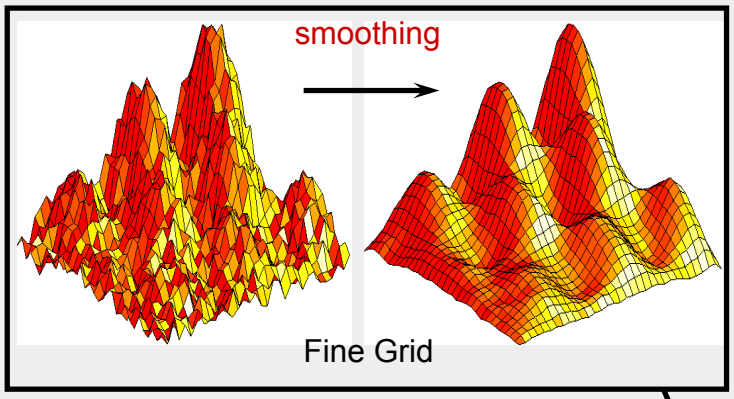
NEW (multi-scale) Algorithms

- We need to resolve many scale physic
  - quarks masses:
    (udscbt = 2, 5, 100, 1300, 4190, 200000 MeV)
  - Electromagnetism (proton-nucleon splitting, g-2)
  - Binding energy of nuclei (2.2 Mev for deuteron)
  - TeV Strong Gauge BSM (near conformal) dynamics for composite Higgs
  - Origin of Higgs, Dark Matter, String Theory.

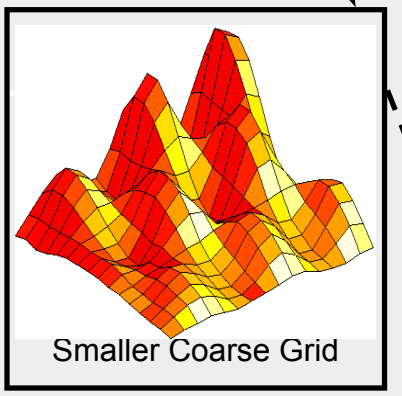


$$\psi_0^{ia}(x) \sim \frac{1}{x^2+\rho^2}\hat{x}_\mu \gamma_\mu^{ik}\frac{(1+\gamma_5)^{kj}}{2}\epsilon^{ja}$$

Adaptive Smooth Aggregation Algebraic Multigrid



restriction



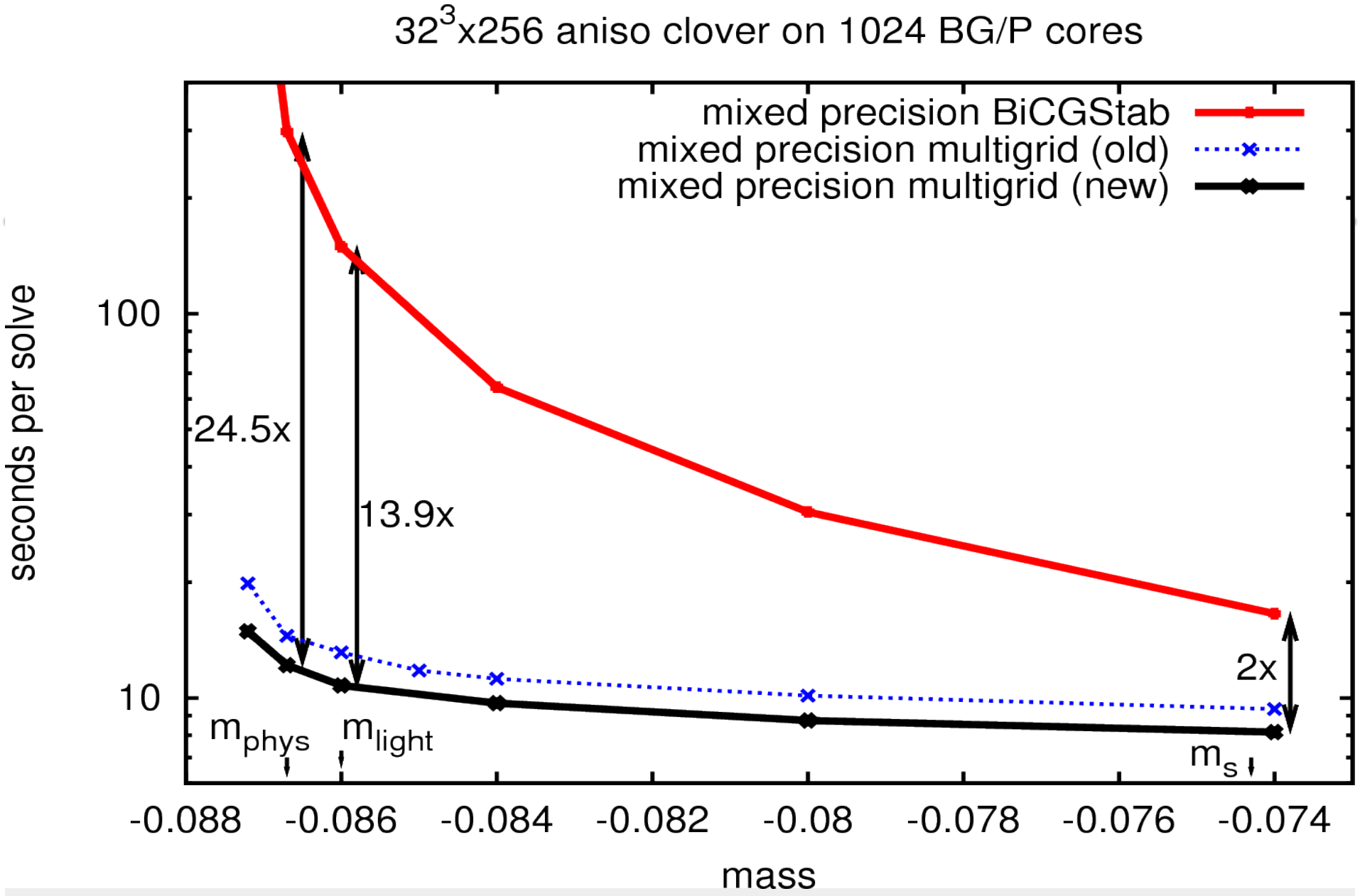
prolongation
(interpolation)

The Multigrid
V-cycle

Spilt the vector space into near null space S and the complement $S_?$

D: S ' 0

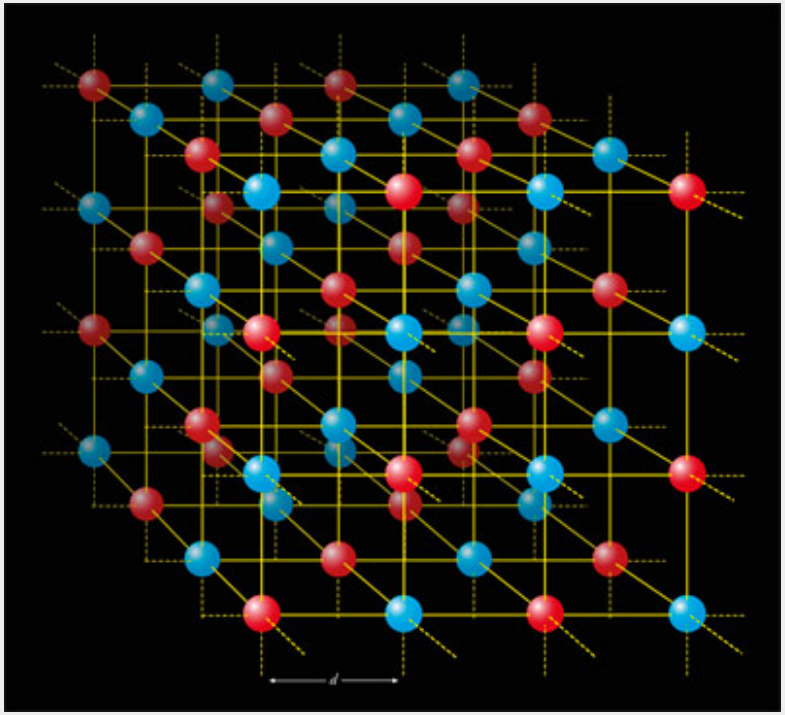
Slow convergence of Dirac solver is due to small eigenvalues for vectors in near null subspace: *S* .



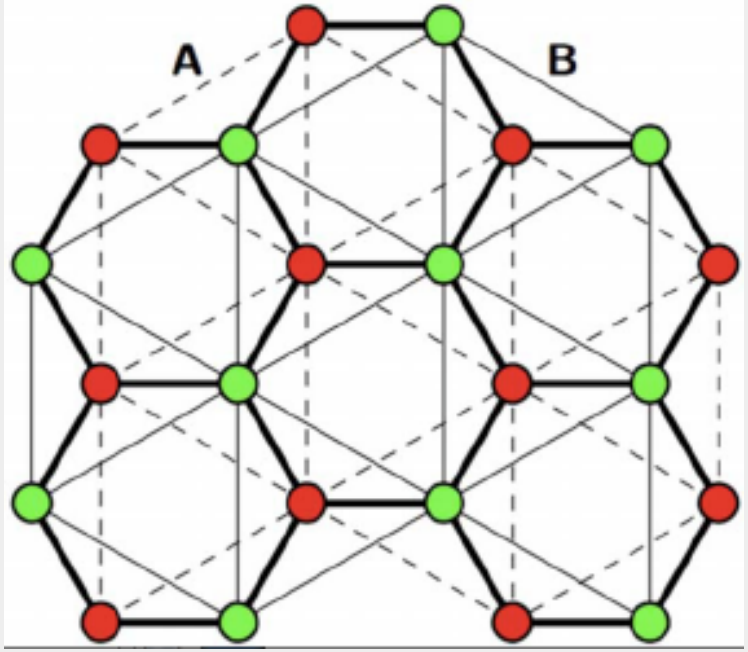
"Adaptive multigrid algorithm for the lattice Wilson-Dirac operator" R. Babich, J. Brannick, R. C. Brower, M. A. Clark, T. Manteuffel, S. McCormick, J. C. Osborn, and C. Rebbi, PRL. (2010).

New Lattice Geometries

Lattice QCD/CFT



Graphene



Radial Quantization for Conformal Field Theories on the Lattice*

New approach to lattice quantization on

$$\mathbb{R}^d \rightarrow \mathbb{R} \times \mathbb{S}^{d-1}$$

Perhaps it would help to start with a lattice specially suited to study CFT and perturb it away from conforality?

*Brower, Neuberger and Fleming, Lattice 2012
(to be published soon!)

Radial Quantization for CFT

- (near) Conformal Field Theories are important
  - BSM walking technicolor
  - AdS/CFT weak-strong duality
  - Model building

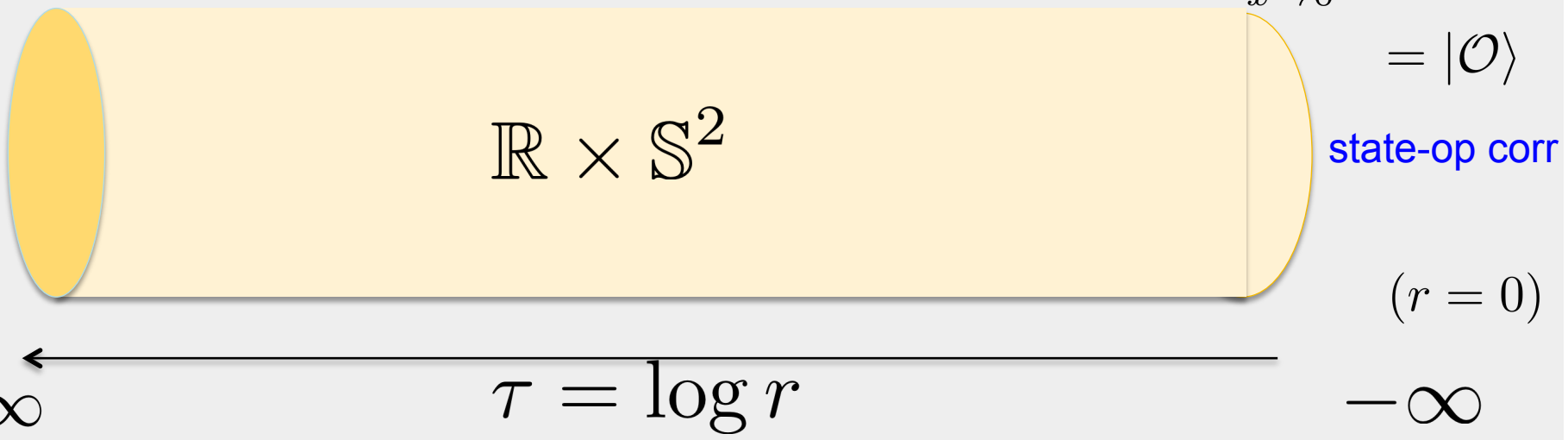
- Lattice difficulty: scales are (nearly) exponential.

- Hypercubic vs Radial Lattice

$$a < \Delta r < L \quad \text{vs} \quad a < \Delta log(r) < L$$

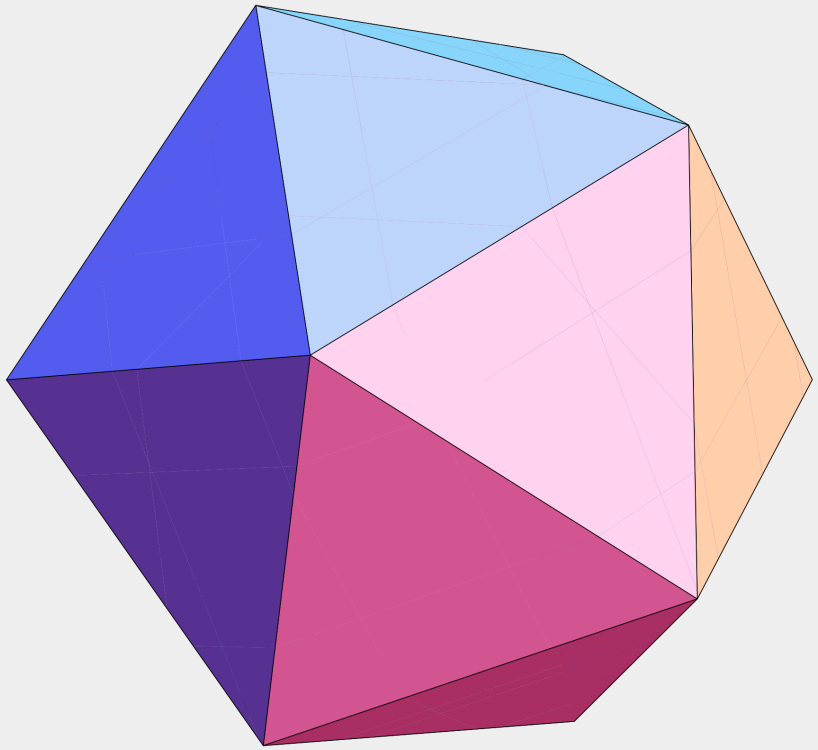
3-d Ising Test of concept

$$Z_{Ising} = \sum_{\{s_{\tau,i}=\pm 1\}} e^{\beta \sum_{\tau,i} s_{\tau+1,i} s_{\tau,i} + \beta \sum_{\tau<i,j>} s_{\tau,i} s_{\tau,j}}$$

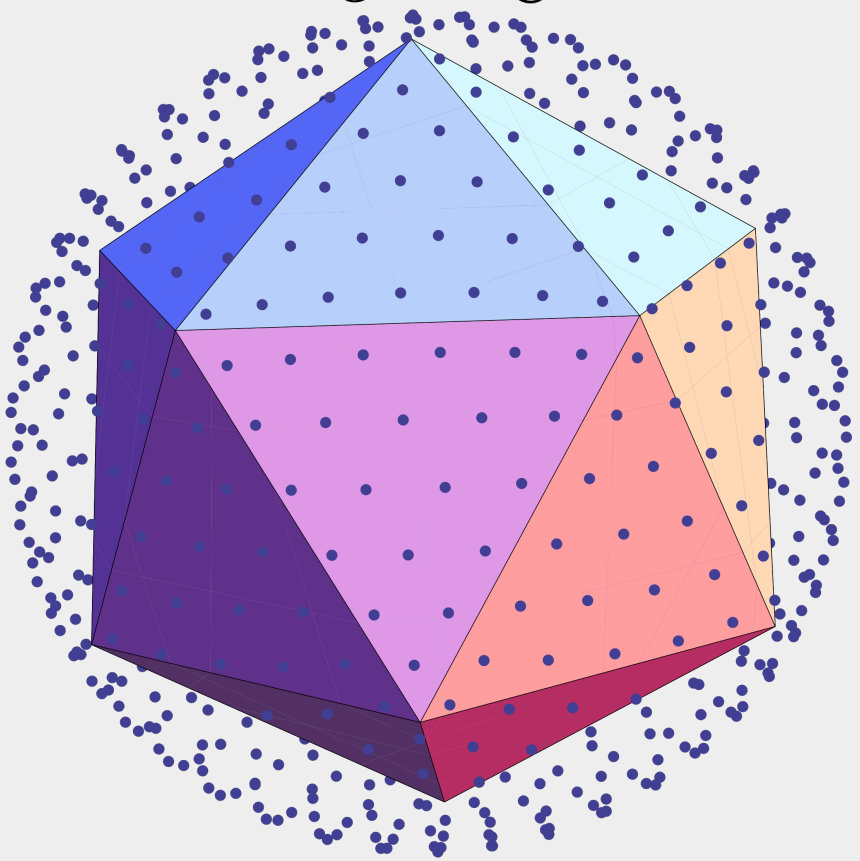


Order s Refined Triangulated Icosahedron

$s = 1$

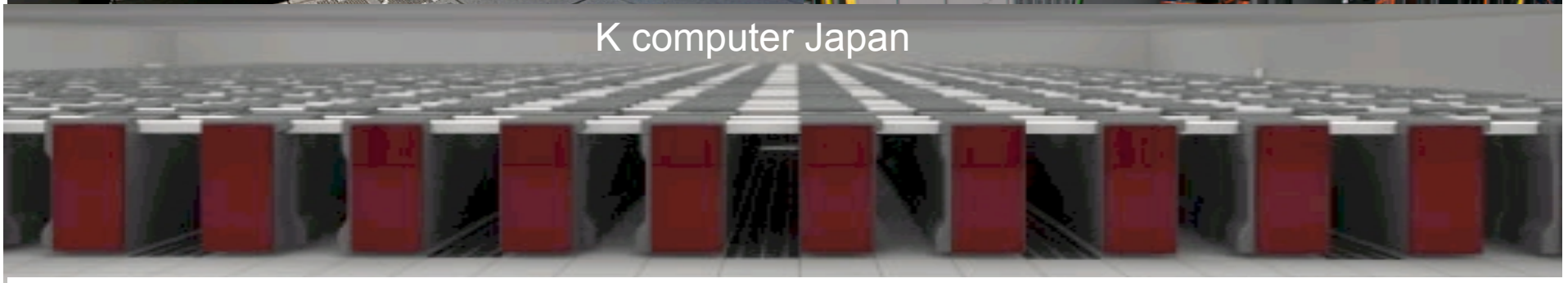


$s = 8$



I = 0,1, 2 irreducible under 120 Ih Iscosahedral subgroup of O(3)

Spectacular Computing Power Doubles every 18 Months
3 Multi-Petaflop/s Machines on Top 500



TOP 500: Cray Titan (United States, November 2012 - present)
IBM Sequoia Blue Gene/Q (United States, June 2012 – November 2012)
Fujitsu K computer (Japan, June 2011 – June 2012)
In 2013+ DOE BG/Q Mira, NSF Cray/Nvidia Blue Waters, Intel/MIC Stampede

Nov. 12, 2012 Titan supercomputer leads latest Top 500 list, newly-available Xeon Phi chip cracks top ten

Cray XK6 Compute Node

XK6 Compute Node Characteristics
AMD Opteron 6200 Interlagos 16 core processor
Tesla X2090 @ 665 GF
Host memory 16 or 32GB 1600 MHz DDR3
Tesla X090 memory 6GB GDDR5 capacity
Gemini high speed Interconnect
Upgradeable to NVIDIA's Kepler many-core processor

Slide courtesy of Cray, Inc.

Disclaimer: No contract with vendor is in place

FUEL
(Framework for Unified Evolution of Lattices)

- New BSM Application Framework:
- Use LUA scripting language interface
  (e.g James Osborn ANL & Andrew Pochinsky MIT)
- Uniform over new Actions with new gauge groups
  and fermions.
- Rapid parameter optimization by Autotuning
  collaboration SUPER institute
  (e.g.Stefan Wild ANL Numerical Optimizatio & G. Fleming Yale)

Step one: MG on GPU

- Cost in $s reduced by a factor of at least

O(100+)

GPU O(10+)

MG O(10+)

Michael Cheng (BU)
and
Ron Babich/Mike Clark
(NVIDIA)

Step Two: Native SU(2) color in FUEL

- SU(2) color with two flavors has 5 GBs in SU(4)/Sp(4) coset
  - 3 Pions to give W+, Z, W- mass
  - 1 PNGB Higgs (pseudo Nambu Goldstone Boson)
  - 1 Dark Matter candidate.

Step Three: MG/QUDA Evolution

- Use FUEL to drive HMC code for SU(2) color
- Use the QUDA Multigrid Inverter
- Use Domain Decomposition to get Strong Scaling on Titan/Cray style architecture.
- Time to achieve this should be 3 years! It not trivial but the rewards should be dramatic!

Discussion?

- Similar to QCD but even more Software demand
- Strong interaction with Exp and Phenomology
- Stronger Applied Math and Computer Science interdisciplinary teams:
  - FASTmath @ LLNL&ANL -- Hyper/MG
  - SUPER @ LLNL & RENCI -- Rose Compiler/Optimization
- Definition of a new Heterogeneous API Message + Threading Environment.