Lattice Strong Dynamics
TeV physics, dark matter, and supercomputers

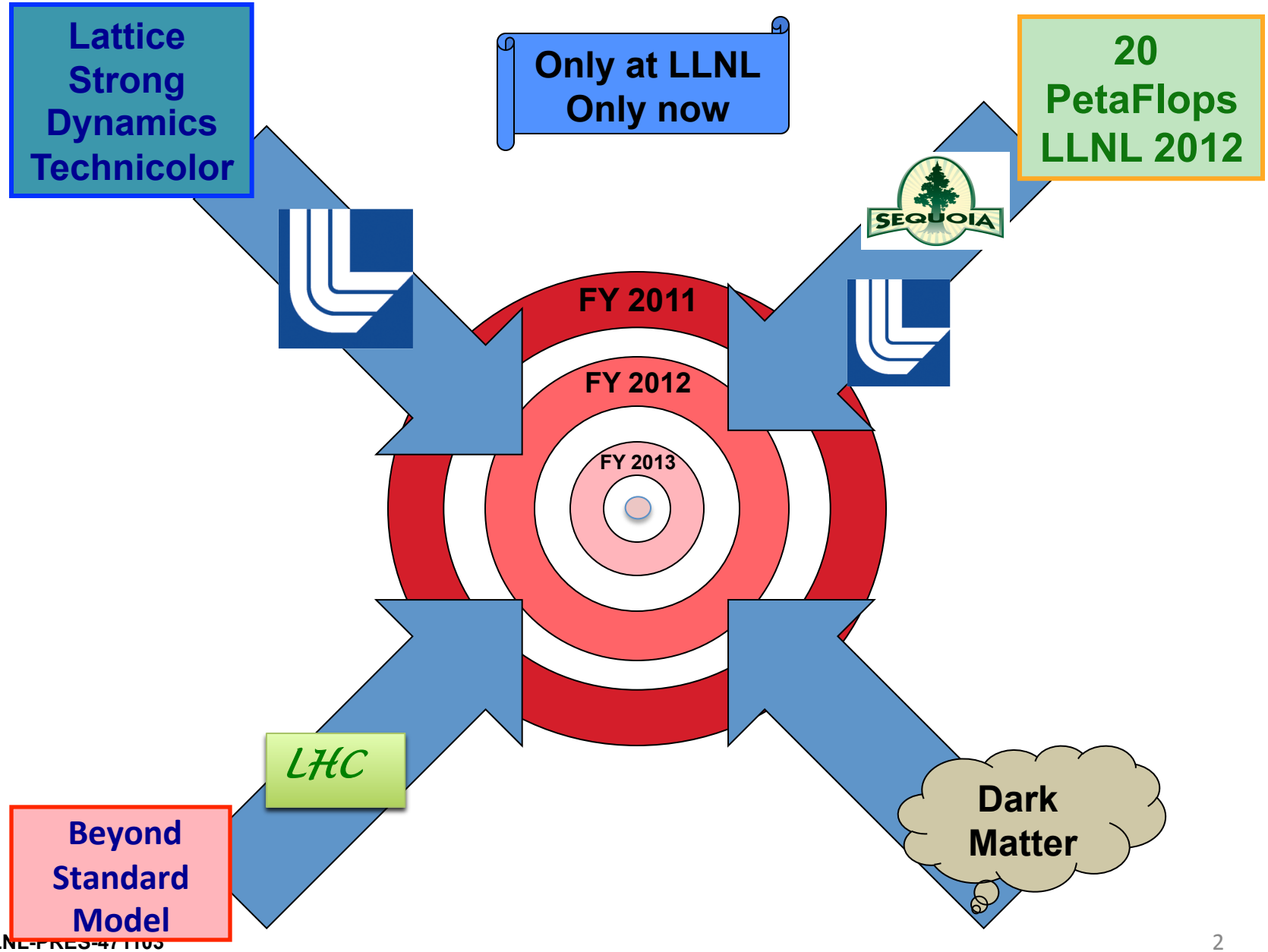
DOE HEP visit, February 2011

Pavlos Vranas

with LLNL postdocs
M. Buchoff
M. Cheng
J. Wasem

LLNL-PRES-471103

A unique confluence



Background

Something old is new again

Technicolor, beyond SM
Small worlds inside small worlds

A new strong force
Techni-quarks
Techni-gluons

Massless SU 2)
Gauge fields

$A_1 \quad A_2 \quad A_3$

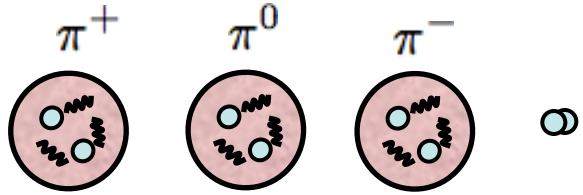
Flavors = # of particle species

Massless particle
fermion fields

$\Psi_e, \Psi_\mu, \ldots$

Spontaneous chiral symmetry breaking by the strong dynamics

$W^+ \quad Z^0 \quad W^-$



$\bar{T}T\bar{\Psi}_e\Psi_e, \ldots$

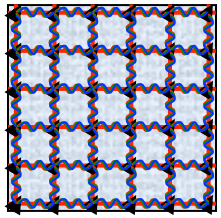
$m_\pi = 0$ $\quad \langle \bar{T}T \rangle \neq 0$

$m_{W,Z} \sim F_\pi^{tc}$ **TC**

ETC $m_e \sim \langle \bar{T}T \rangle, \ldots$

Technicolor demands

- Technicolor like QCD is strongly interacting.
- Strongly interacting theories can only be studied numerically on the Lattice.
- They are extremely demanding computationally.



- Sample cases need ~0.5 PetaFlops (BG/L, BG/P).

- Reliable studies need 10 – 20 PetaFlops (Sequoia).

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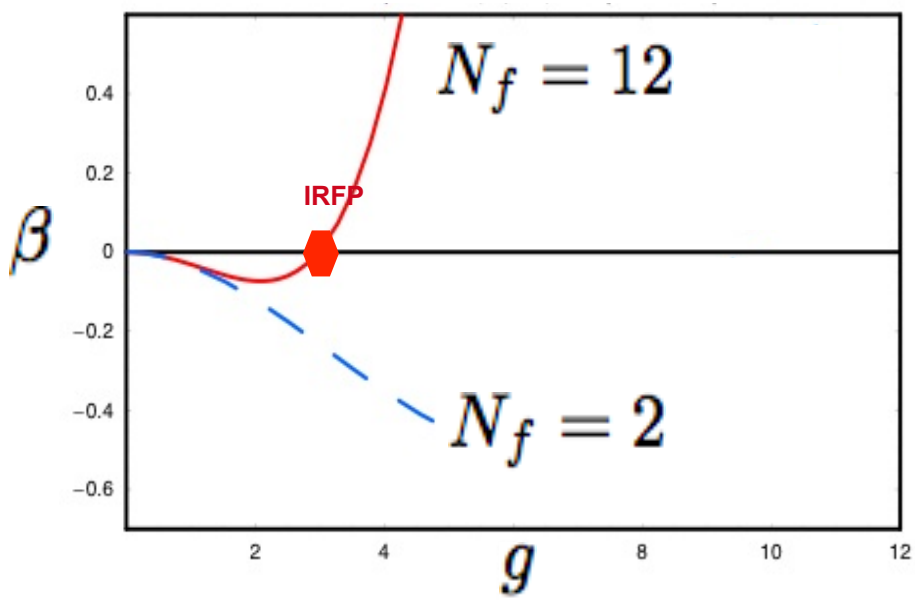
Walking

- Technicolor is not flavor-scaled up QCD. Near an IRFP it walks.

Perturbative beta function



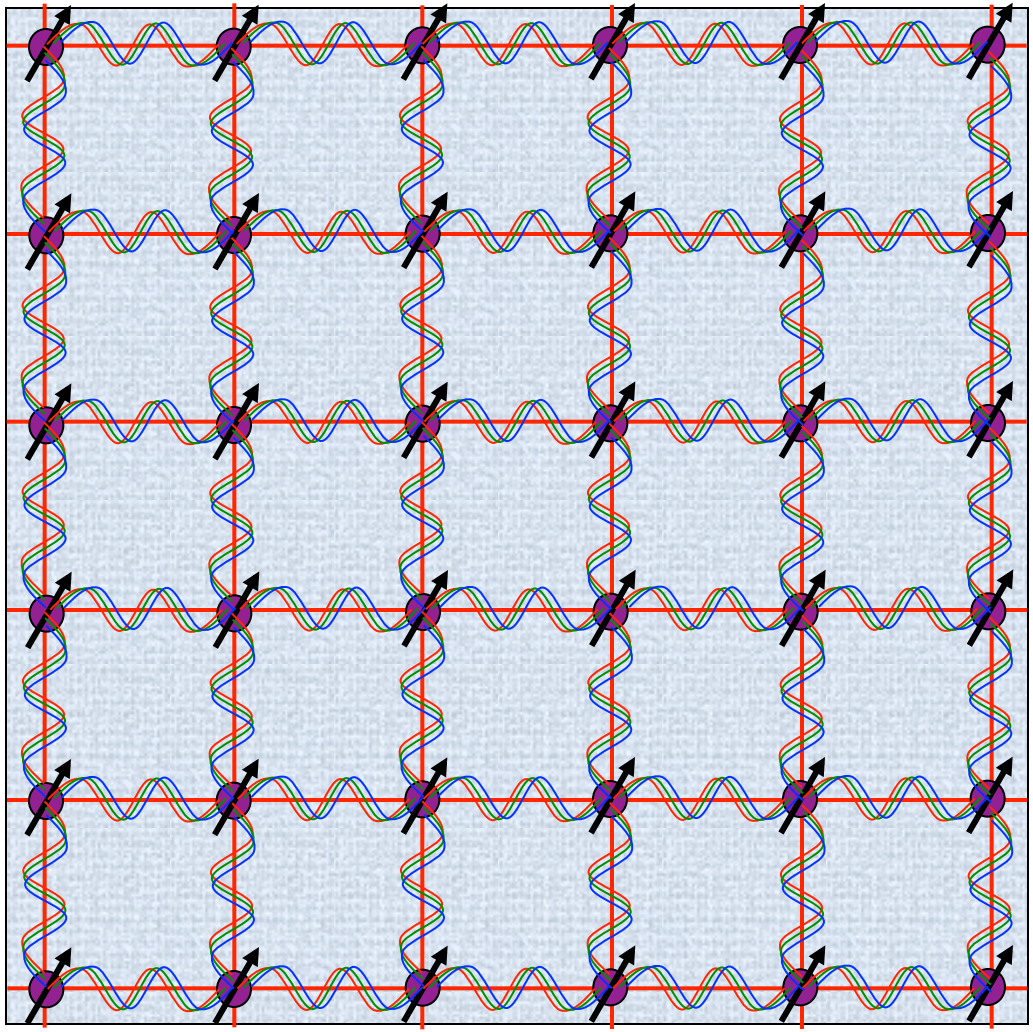
- Naïve scaling with number of flavors gives wrong results.
- Flavor changing neutral currents may not be a problem :

  Condensate enhancement
- Precision Electrweak measurements may not be in tension with TC :

  S parameter

The lattice

GapDWF Innovation

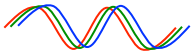


Continuum

4-dimensional

Lattice

Fermion spinor Y
Nf per site



Gauge field U

Nc x Nc matrix
per site

Nf = number of flavors

Nc = number of colors

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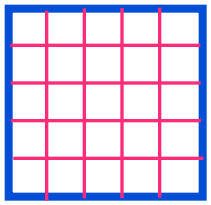
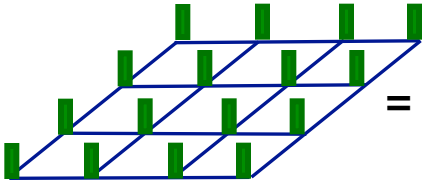
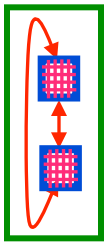
Massively parallel layout



= one core with
a sub-lattice

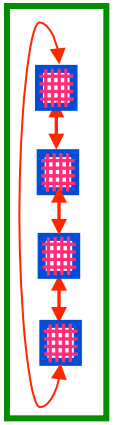


= one rack
of chips

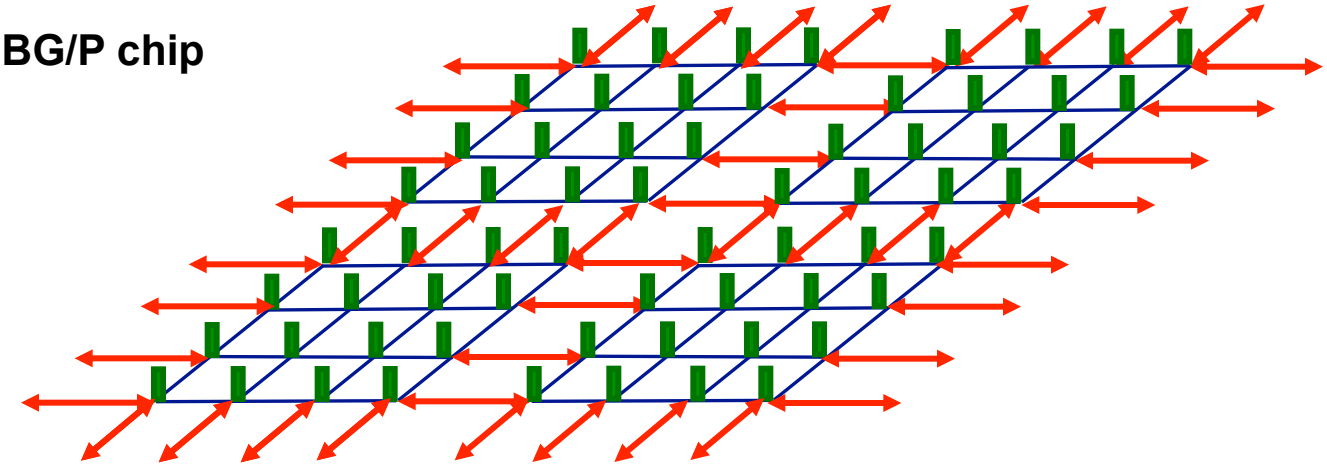


= = one BG/L chip

= Inter-rack
torus
interconnect



= = one BG/P chip



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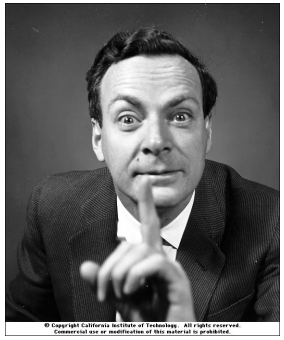
LLNL BlueGene/L

R. Feynman and the Connection Machine

By W. Daniel Hillis. Physics TodayFebruary 1989
http://www.kurzweilai.net/articles/art0504.html?printable=1

"R. Feynman played a critical role in developing the first parallel-processing computer…"



"… I mentioned to him that I was planning to start a company to build a parallel computer with a million processors. His reaction was unequivocal, "That is positively the dopiest idea I ever heard."

"… his assignment would be to advise on the application of parallel processing to scientific problems. "That sounds like a bunch of baloney," he said. "Give me something real to do. "So we sent him out to buy some office supplies."

"…When Richard returned from buying pencils, we gave him the assignment of analyzing the (message) router…Richard began studying the router circuit diagrams as if they were objects of nature."

"… he had to write a computer program for QCD…. He was excited by the results. "Hey Danny, you're not going to believe this, but that machine of yours can actually do something *useful* !"

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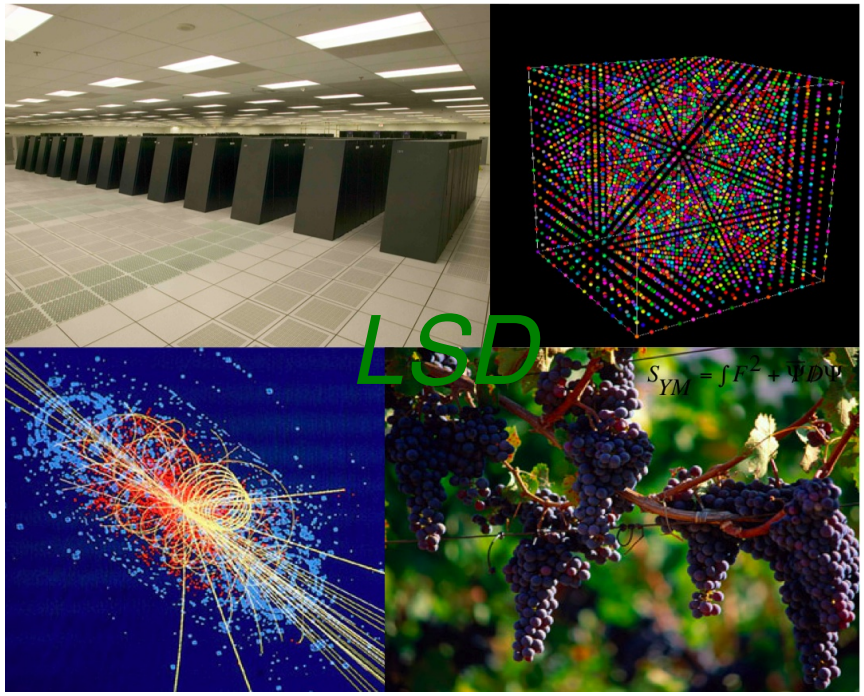
The Program

Leading the Lattice Strong Dynamics collaboration

T. Appelquist	Yale U.
R. Babich	Boston U.
R. Brower	Boston U.
M. Buchoff	LLNL
M. Cheng	LLNL
M. Clark	Harvard U.
S. Cohen	Boston U.
G. Fleming	Yale U.
G. Voronov	Yale U.
F. Jiang	MIT
J. Kiskis	UCD
M. Lin	Yale U.
E. Neil	Fermilab
J. Osborn	ANL
C. Rebbi	Boston U.
D. Schaich	Boston U.
S. Syritsyn	LBNL
P. Vranas	LLNL
J. Wasem	LLNL



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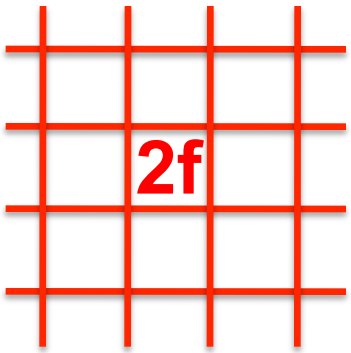
Goals

- Is Technicolor a viable theory for beyond SM?
- Technicolor signatures at LHC?
- Technicolor nuclear properties. Viable dark matter candidate?
- TC and ETC phenomenology can use lattice non-perturbative input.
- How do the properties of gauge theory change with N_f, N_C?
- Technicolor and High Performance Computing

Projects:

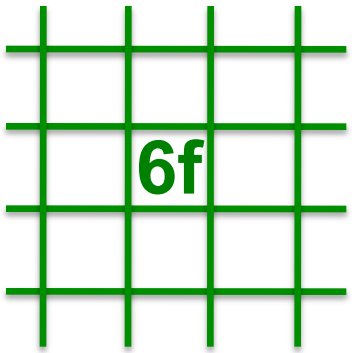
SU(3c) Lattice generation. On disk at LLNL.

- More than 350 Million LLNL BlueGene/L core hours so far (~2 years)
- More than **$2 Million dollars** (at 6c / core hour)
- Similar to all USQCD combined
- Unique in the world. Enormous wealth for post processing
- Will make available to the community after we conclude our projects



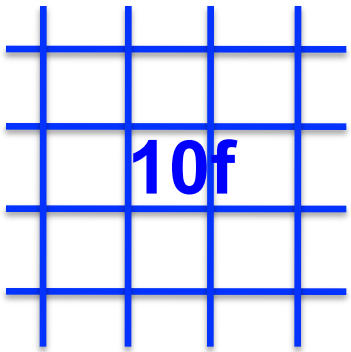
~800 lattices / mass
six masses

Done



~800 lattices / mass
six masses

80% Done



~400-800 lattices / mass
six masses

70% done

32^3x64, DWF with L_s=16, $m_\pi L > 4$, Cutoff ~ 40 f_π ~ (matched)

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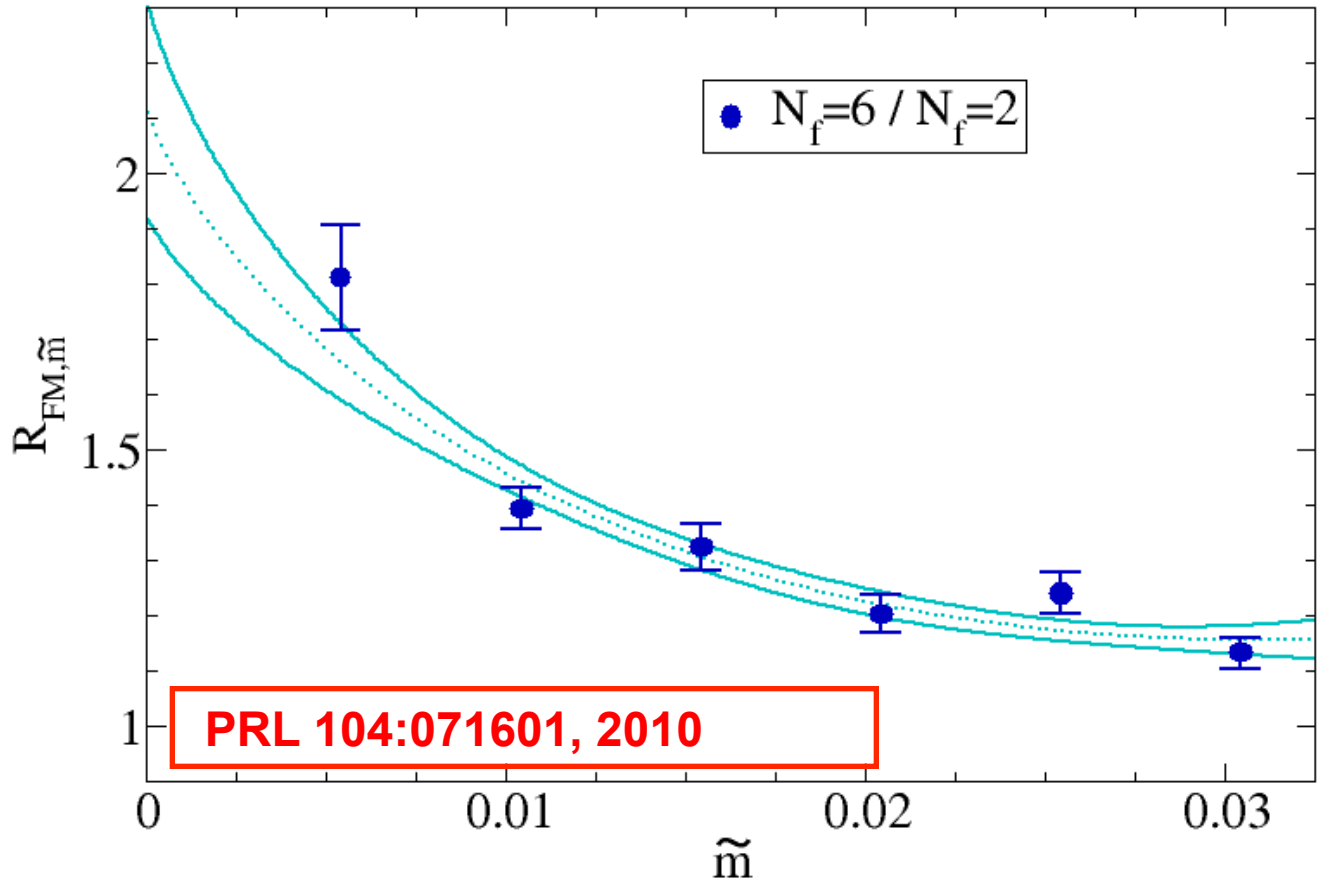
6-flavor over 2-flavor condensate enhancement



PRL 104:071601, 2010

Is ETC viable?

★ $R_m = [M_m^2/2mF_m]_{6f} \quad / \quad [M_m^2/2mF_m]_{2f}$

★ Can compare directly 6f to 2f because they have same cutoff

★ Observing **~ 50% enhancment**

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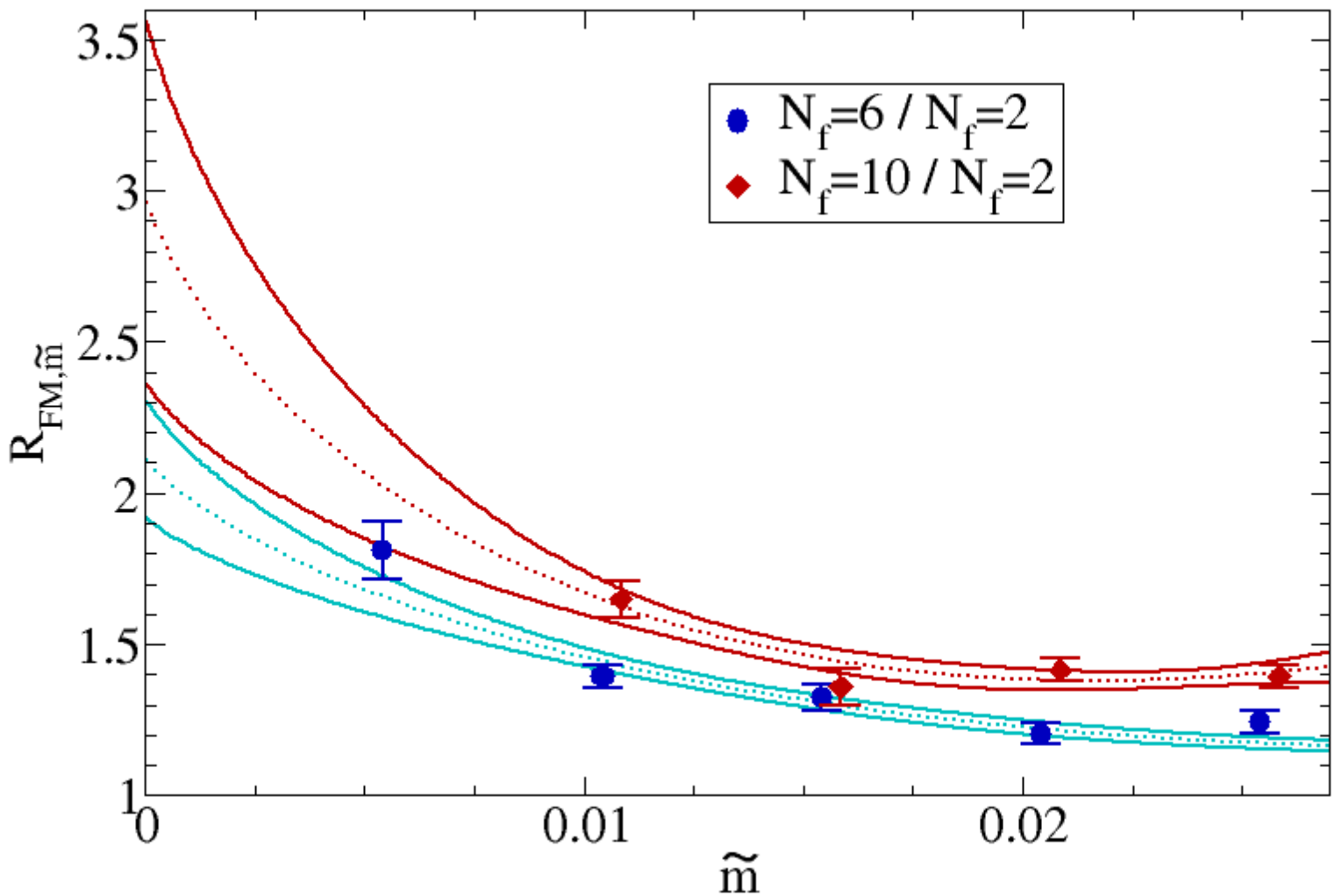
10 and 6 flavor over 2-flavor condensate enhancement



Is ETC viable?

✦**Very Preliminary:** Observing more enhancement at 10f

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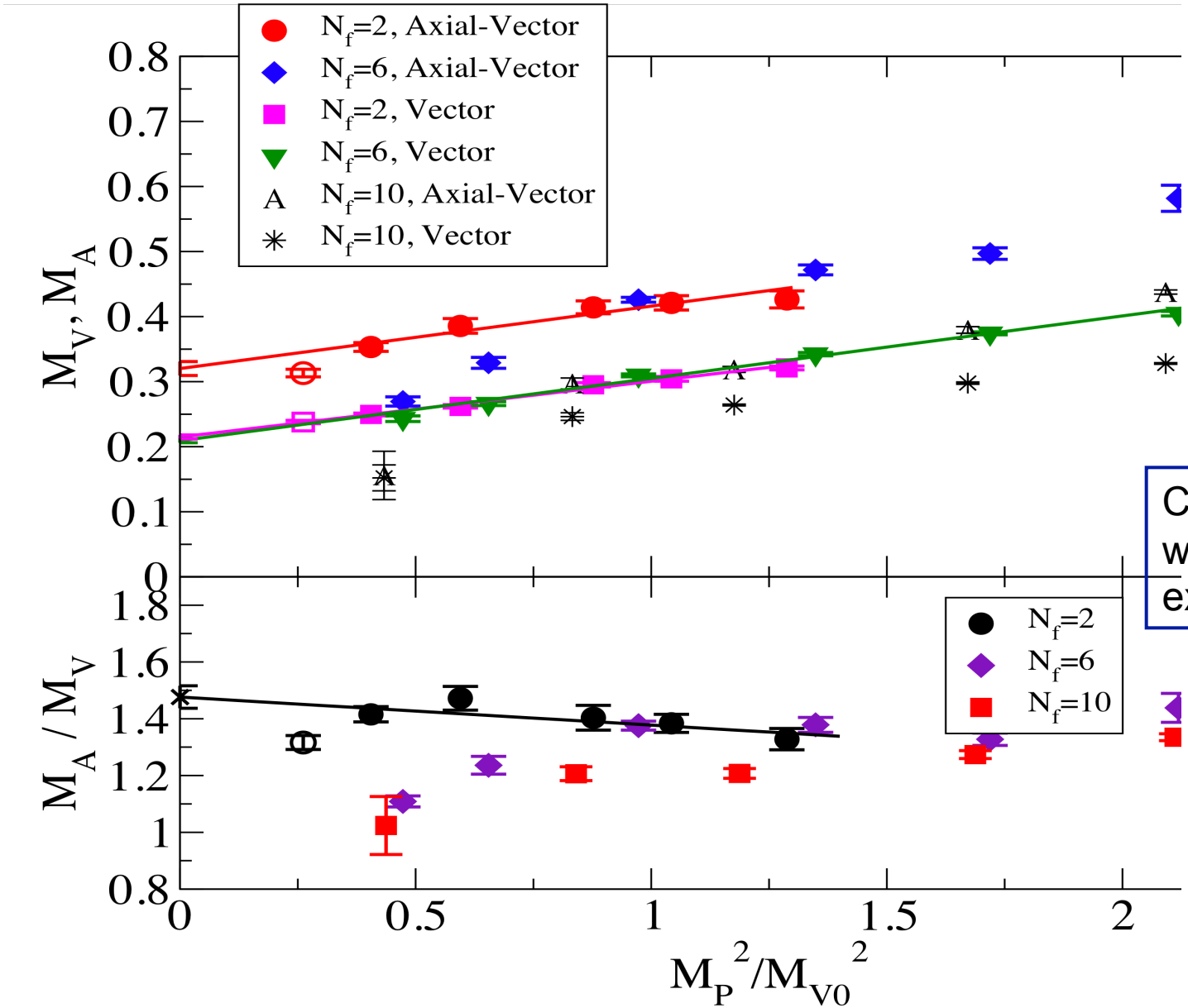
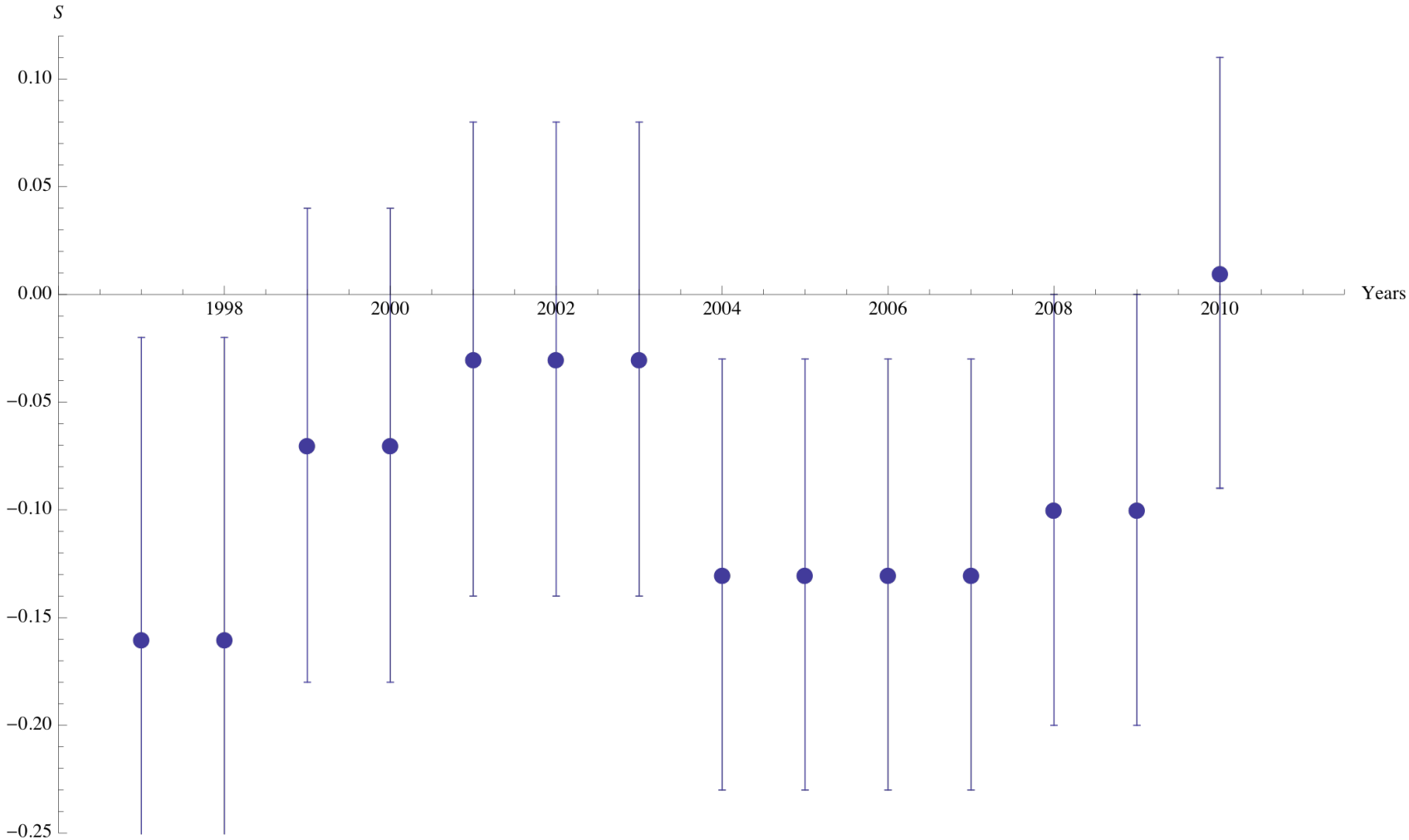
Axial and vector masses: Parity doubling



LHC signatures?

Collaborate with LLNL experimentalist

S parameter (experiment) over time (PDG)



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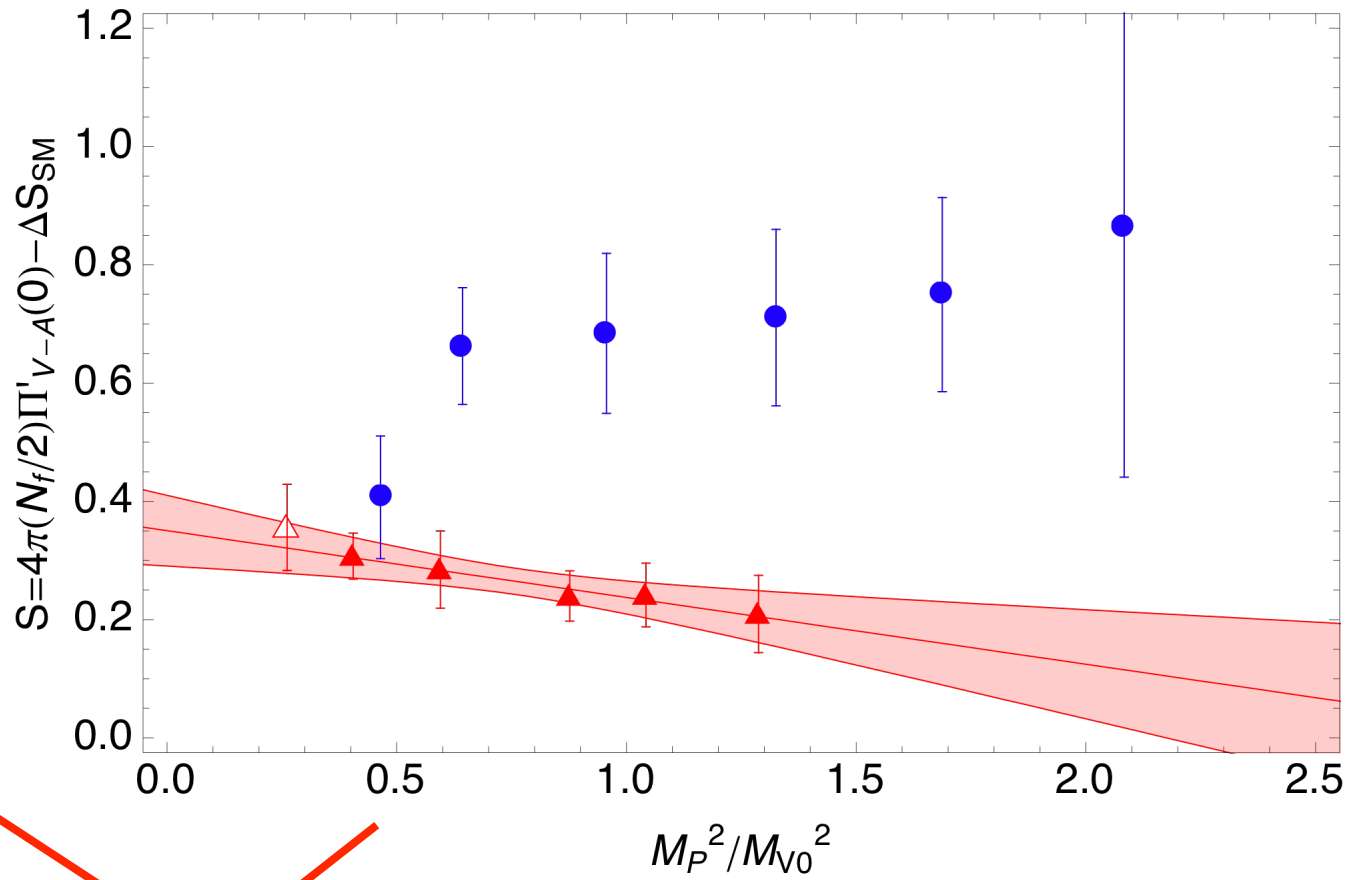
S parameter SU(3c) numerical results

Is TC viable?



$N_f = 6$

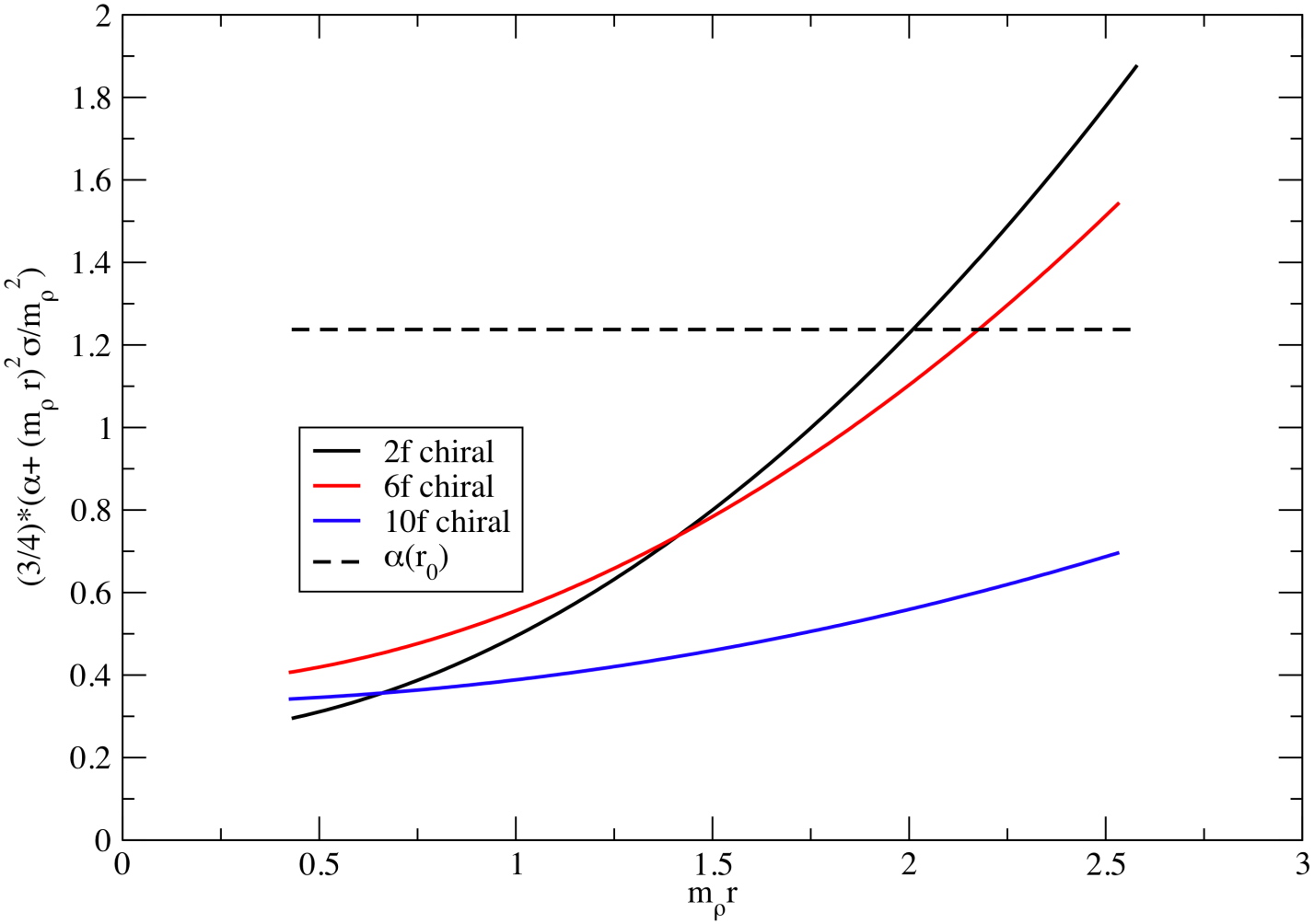
$N_f = 2$

$$S \simeq 0.25 \frac{N_F}{2} \frac{N_C}{3}$$

PRL, final review, 2011

Running coupling

Strength of the new force ?



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Eigenvalue spectrum

Detailed understanding of TC/ETC?

- ⌘ **Measure the lowest 100 eigenvalues for 2f, 6f and 10f**
- ⌘ **Extract chiral condensate directly from Banks-Casher**
- ⌘ **Calculate anomalous dimension**

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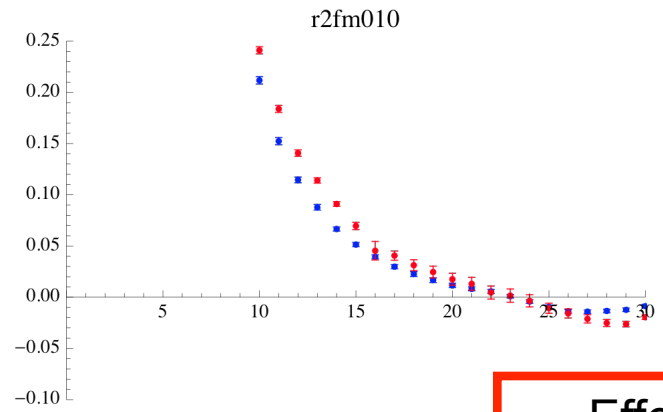
Techni pion interactions.

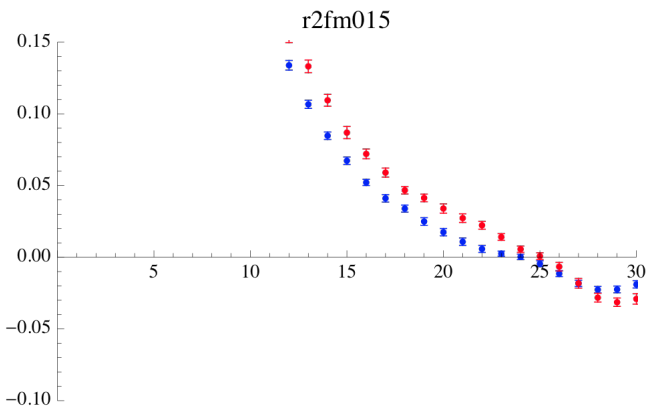
New
Pilot
study

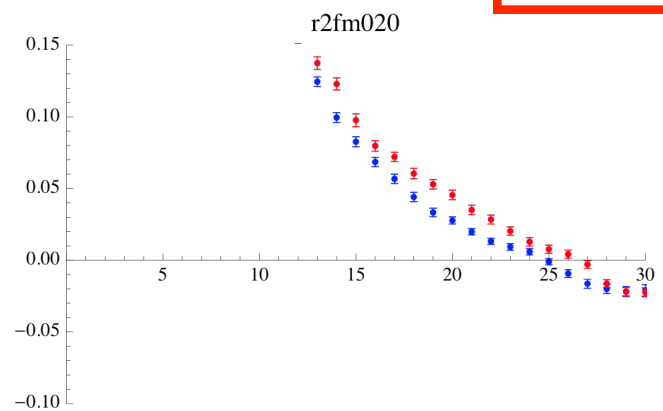
Techni-pion = W, Z longitudinal
➔ WW scattering ➔

blue = 2f, red = 6f
Interaction vs. time slice
Mass = 0.01, 0.015, 0.02



Effects on
WW scattering ?





Techni-nucleon form factors and dark matter

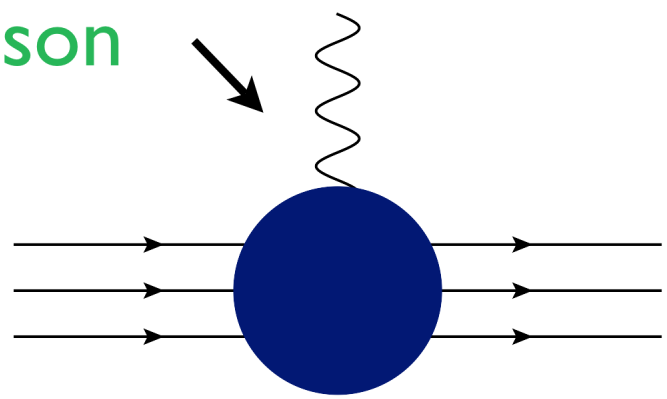
New Pilot study

- ⌘ Technicolor has a stable baryon
- ⌘ It can be Electro-Weak neutral
- ⌘ It may have a dipole moment
- ⌘ How strong is the interaction? ➔ Calculate form factors
- ⌘ It is a viable candidate for dark matter

Dark Matter Candidate?

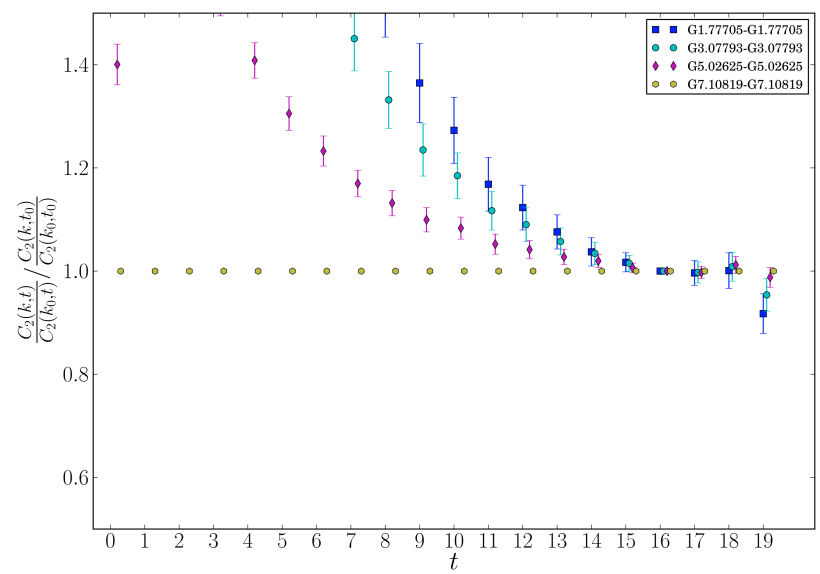
Collaborate with LLNL detection

EW vector boson



G_E

Operator smearing test



The vacuum channel, 0++

New
Pilot
study

Is there a particle in 0++ ?

- ⌘ Dilaton ?
- ⌘ Sigma ?
- ⌘ Glueball ?

Techni thermodynamics

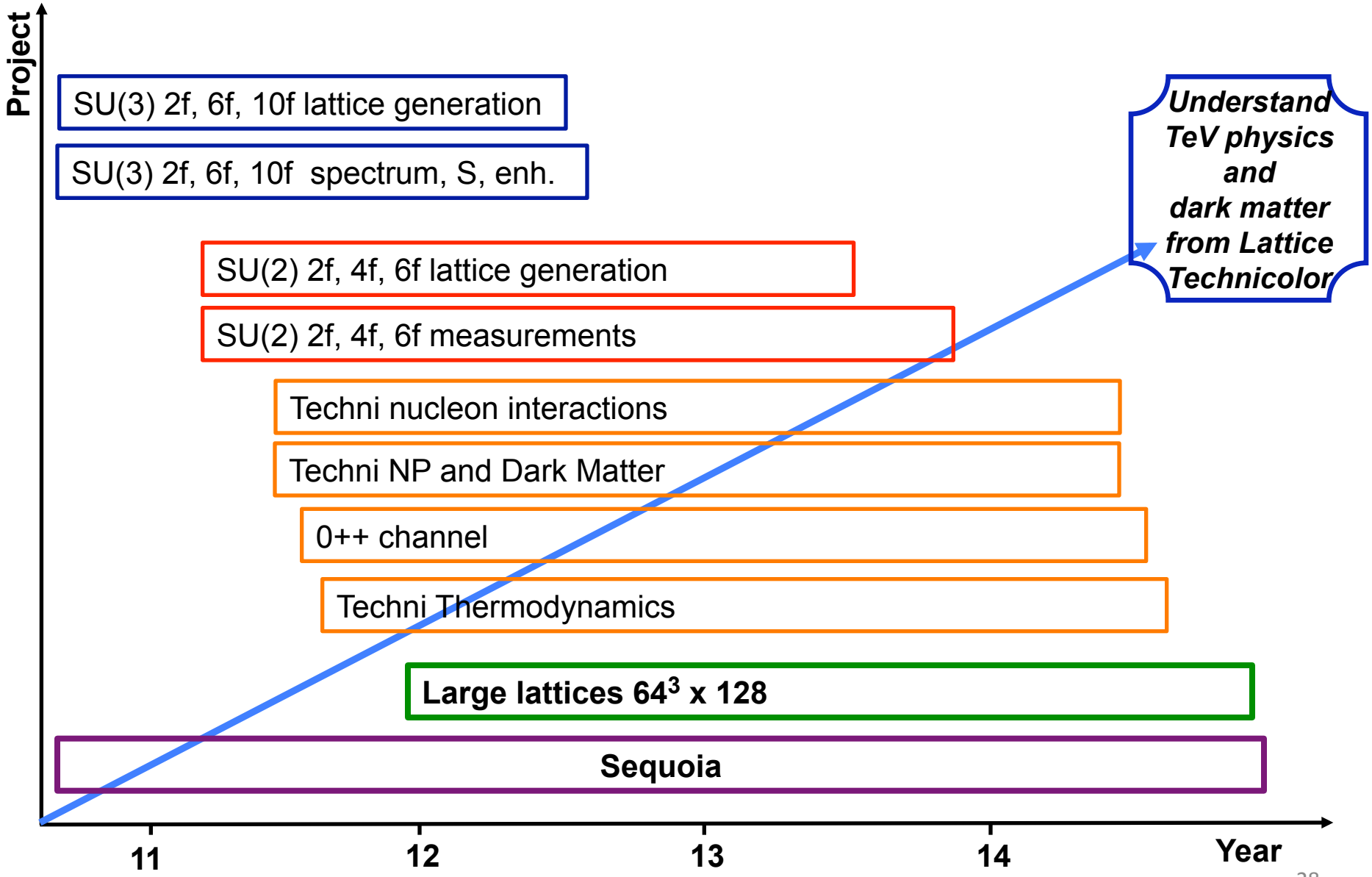
New
Pilot
study

Transition ?

- It should have a techni quark – gluon plasma phase.
- Another “cosmic” phase transition?
- What is the order?
- How much is Tc/rho ? In QCD it is ~0.2.

Plans

Timeline



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The Elephant in the Room :
A singular opportunity

Sequoia (BG/Q) for LSD, a singular opportunity

- A 20 PetaFlops supercomputer.
- To be operational at LLNL in late 2011.
- 40 times faster than our current BG/L/P

We now have access to IBM Sequoia hardware simulators and first prototypes.

We must start writing LSD kernels ASAP

Unprecedented possible opportunity for the next 6 years.
Must be ready for Spring 2012

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LLNL Supercomputing activities

- ★ Part of the core hardware architecture team of Sequoia
- ★ Part of the R&D team and LLNL procurement team
- ★ Will develop highly optimized codes
- ★ Our synergistic contribution to LLNL/NNSA and DOE/HEP

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Would you like a 30 min tour?

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Activities

The Berkeley Livermore Lattice Group

Pavlos Vranas

Wick Haxton

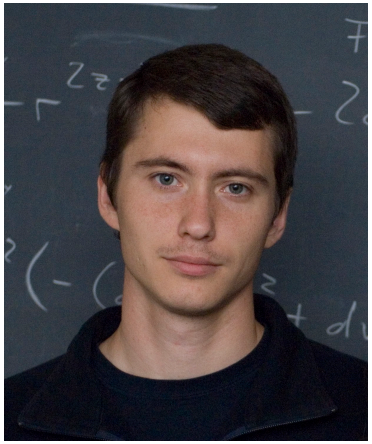
Ron Soltz

Tom Luu

Andre Walker-Loud

Mike Buchoff

Michael Cheng



Sergey Syritsyn

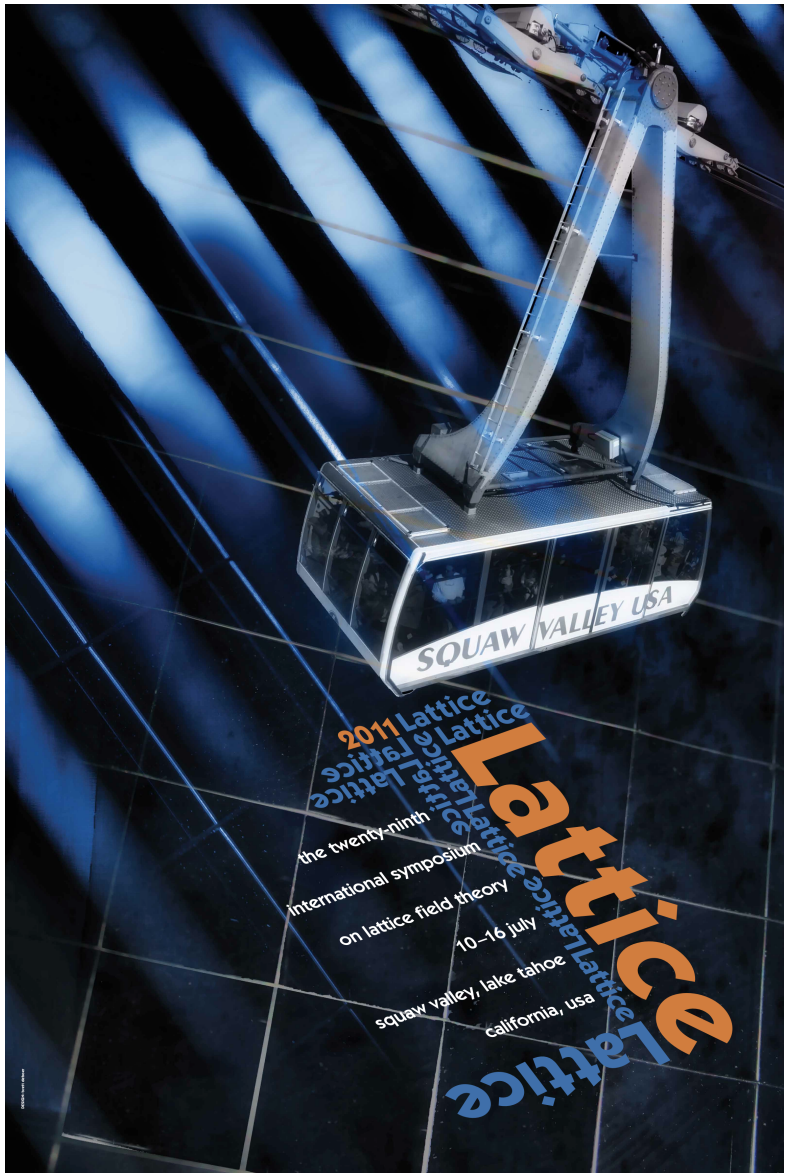
Joe Wasem

LLNL Lattice 2011 international conference host

P. Vranas chair

California LOC, 17 members

6 LLNL and 2 LBNL members



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Funding

Funding

	FY10	FY11	FY12++ baseline
DOE HEP	0.25 FTE $120K	0.25 FTE $120K 0.5 PD $75K	0.25 FTE $120K 1.0 PD $150K
LDRD HEP	0.5 PD $75K	0.5 PD $75K	0
Total	0.25 FTE 0.5 PD $195K	0.25 FTE 1.0 PD $195K + 75K ---------- $270K	0.25 FTE 1.0 PD $270K

-- current
-- requested

1 PD = $150K
1 FTE = $480K

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Funding increase request of +1PD = +$150K

Crucial to sustain the activity
and take advantage
of the Sequoia LLNL 20 PetaFlops supercomputer

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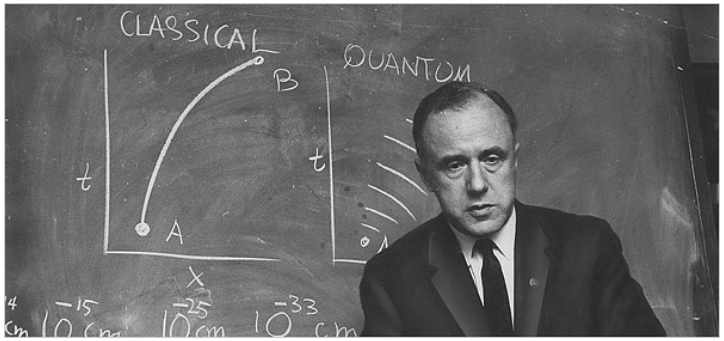
Conclusion

Extremes

J.A. Wheeler

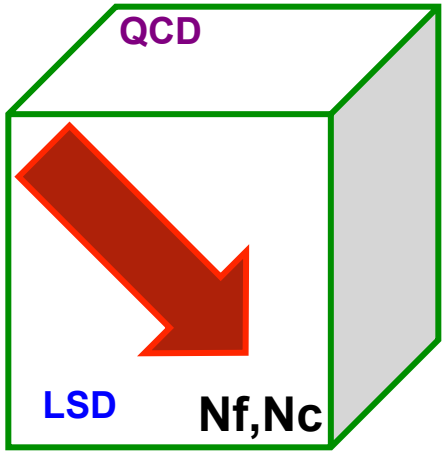
Geons, black holes and quantum foam, p 232

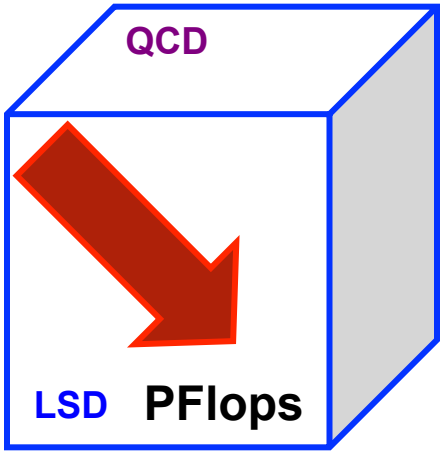


… nature would avail itself of all the opportunities offered by the equations of valid theories.

If nuclei could exist in doughnut shapes, I felt, that some of them would exist in such shapes.

We physicists should think about where such extreme behavior might occur, and look for it.





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