

# Conference Summary

**I'd like to blame the organizers  
for making me give this talk!**

“Thank you again for the kind invitation to give the summary talk at the workshop on CP violation. Unfortunately, couple of days ago I found out that have some official obligations in Novosibirsk and Moscow just March 20-28. Therefore, unfortunately, I will not be able at all to participate in the workshop. I am truly sorry for that.

Sincerely yours,  
Iosif Khriplovich”

**Brad Filippone  
INT Workshop 3/23/07**

# Options for Workshop Closing Talk

- Show everyone's slides *really!* fast
- Attempt to mention every speaker and what they talked about
- Treat the conference as a fine local meal
- Make fun of everyone's talk and include lots of inside jokes
- Ignore the conference and talk about your own work
- Make random predictions for the future of the field

# A. Soni

## Conference Record

### 74 slides (or was it 99!)

And now for a quick review...



Penguins are the key at the Super  
B-factory

# A Nice Dinner in Seattle

- Lincoln whets our appetite with an historical summary of CP violation

**A White Columbia Valley wine with  
Homemade Hummus appetizer**

# CP History

1964 -  $\epsilon = 2 \times 10^{-3}$

CP violation in  $K-\bar{K}$  mix

1993-2003  $\epsilon' = 4 \times 10^{-6}$

CP in  $K$  decay amplitude

2001 - 2006  $\sin 2\beta = 0.7$

CP in  $B-\bar{B}$  mixing

2004 - 2006  $A(B \rightarrow K^{\pm} \pi^{\mp}) = -0.1$

CP in  $B$  decay amplitude

# LESSONS FROM THE PAST

FITCH-CRONIN

EXPERIMENTALISTS CAN  
IGNORE THEORY AND

WEINBERG

THEORISTS CAN  
IGNORE EXPERIMENT AND

KOBAYASHI-MASKAWA

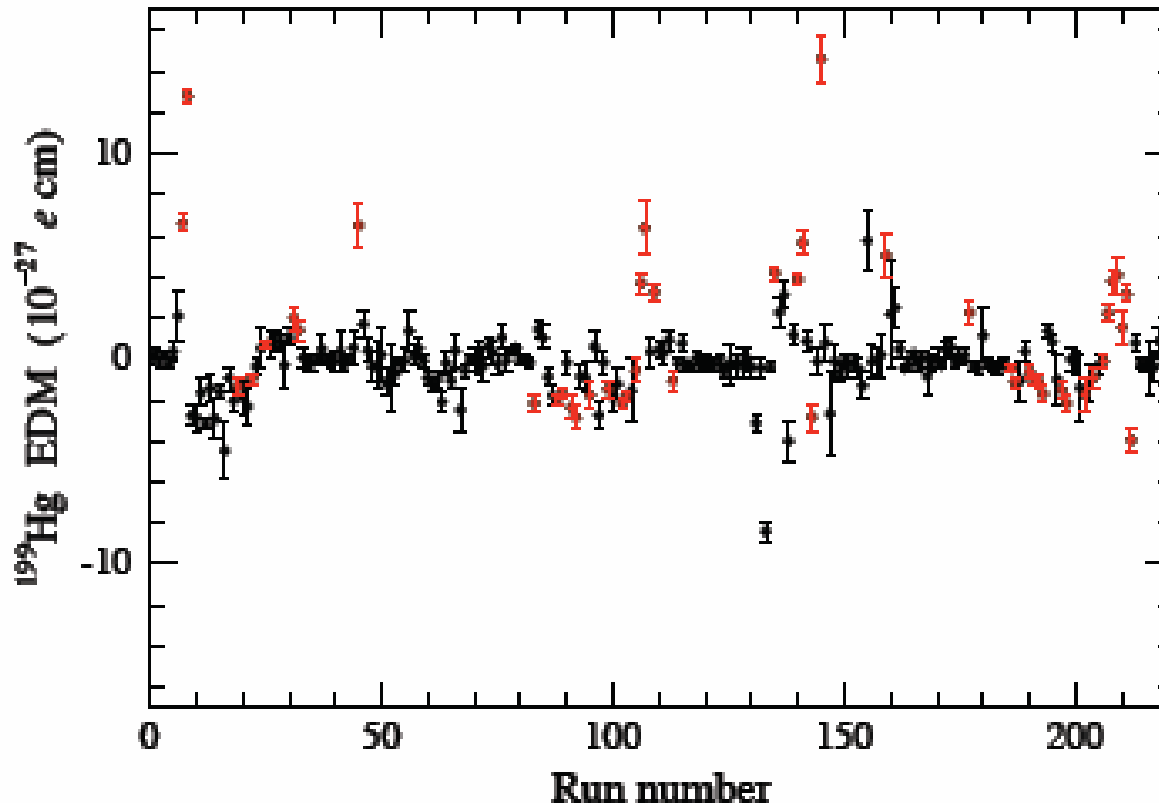
THE NEW PHYSICS AT  
A HIGH MASS SCALE  
MAY NOT BE VERY HIGH

- Clark Griffith starts to fill us up with new  $^{199}\text{Hg}$  data

**Salad with candied walnuts and organic field greens with a Nicoise Vinaigrette**



## 4 cell data: 2002 – 2004

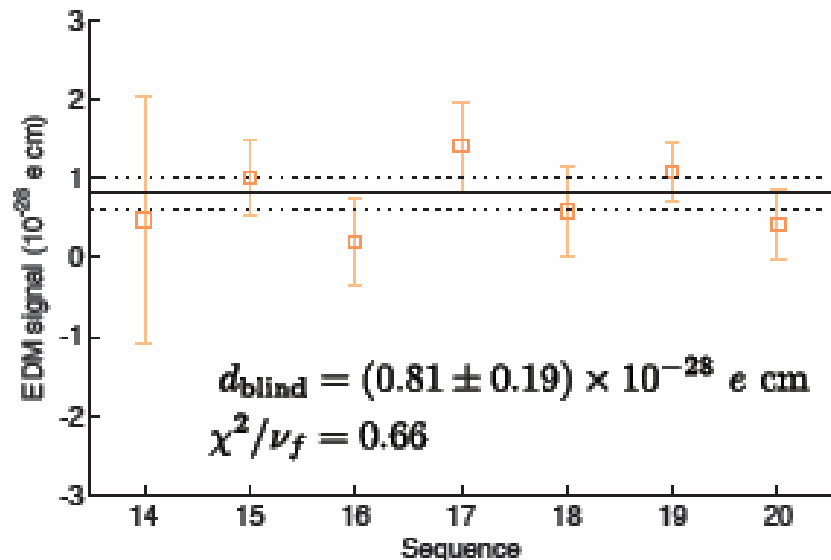


- 160 days of data with Electric field in 220 data runs.
- About 100 of these runs shows signs of a significant HV correlated frequency shift

**Beware! – may lead to indigestion<sup>4</sup>**

# I feel better already!

EDM data since August 2006

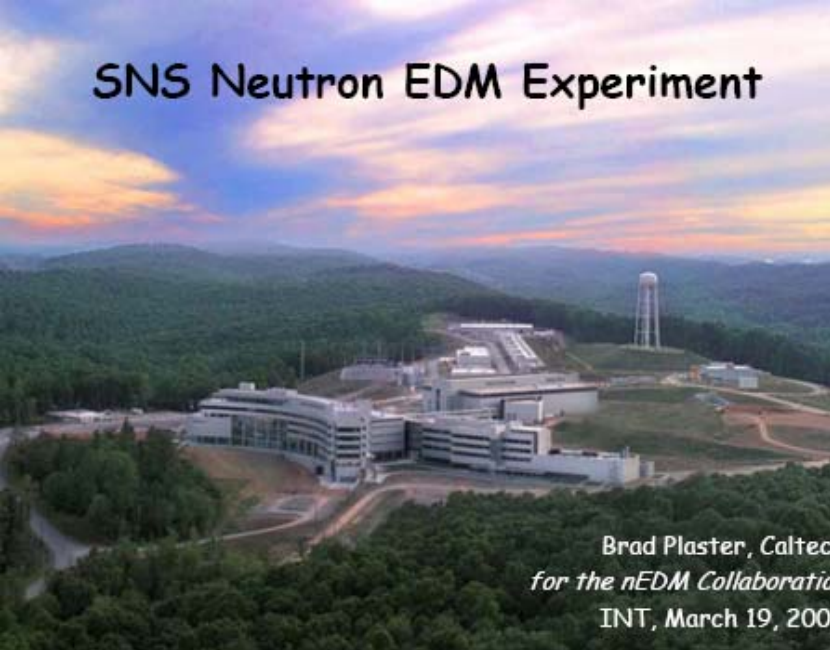


- 4-cell  $^{199}\text{Hg}$  measurement is on track to reach a new result in 2007 with:
  - $\sigma_{\text{stat}} = 1.5 \times 10^{-29}$  e cm
  - $\sigma_{\text{syst}} = 1.5 \times 10^{-29}$  e cm?
  - central value?

- Brad, Klaus, Chen-Yu, Yannis, Seung-Kyun, Jeff, Tim and Aaron provide a solid foundation for the future (is any of this a little fishy??)

**Chilled Poached Wild King Salmon with Red Flame Grape-Shallot-Mint Relish with a (not too heavy) Merlot**

# SNS Neutron EDM Experiment



Brad Plaster, Caltech  
for the nEDM Collaboratio  
INT, March 19, 200

## Laser-trapped Ra-225 for an electric dipole moment search



Argonne  
NATIONAL  
LABORATORY

*J. R. Guest, N. D. Scielzo, I. Ahmad, K. Bailey,  
J. P. Greene, R. J. Holt, Z.-T. Lu, T. P. O'Connor,  
D. H. Patterson, J. W. Wang*

*March 20th, 2007  
INT EDM and CP violation workshop, U. of Washington*

*Department of Energy, Office of Science, Nuclear physics*

## Phase I: OILL@ILL O&M + R&D



fruitful discussions with the colleagues of the former  
RAL-Sussex-ILL collaboration are gratefully acknowledged

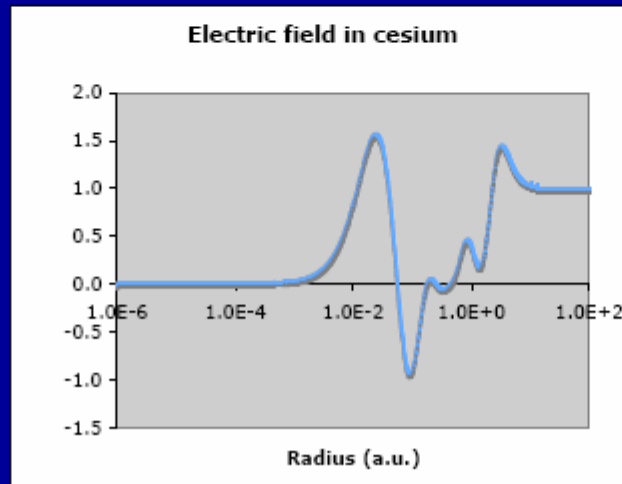
- With a few eclectic side dishes:
- Vladimir tells us about the latest high precision Atomic Physics calculations

**Fresh sea scallops, lightly grilled and served with a soy and black vinegar dipping sauce**

# The correlation potential

Use the Feynman diagram technique to include three classes of diagrams to all orders:

## 1. electron-electron screening



V. Dzuba

# Thanks to Victor!

## EDMs of atoms of experimental interest

Z	Atom	[S/(e fm <sup>3</sup> )]e cm	[10 <sup>-25</sup> η] e cm	Expt.
2	<sup>3</sup> He	0.00008	0.0005	
54	<sup>129</sup> Xe	0.38	0.7	Seattle, Ann Arbor, Princeton
70	<sup>171</sup> Yb	-1.9	3	Bangalore, Kyoto
80	<sup>199</sup> Hg	-2.8	4	Seattle
86	<sup>223</sup> Rn	3.3	3300	TRIUMF
88	<sup>225</sup> Ra	-8.2	2500	Argonne, KVI
88	<sup>223</sup> Ra	-8.2	3400	

$$d_n = 5 \times 10^{-24} \text{ e cm } \eta, \quad d(^3\text{He})/d_n = 10^{-5}$$

- Michael tempts us with hints that EDMs can account for OR rule out Electroweak Baryogenesis

**A plate of Fava beans and a nice Chianti**



- Peter, Pieter and Kazimierz provide the finishing touch to a perfect meal

## **Totally Thai Tiramisu**

Moving from the ridiculous to the sublime...

# "Surprises in Seattle"

- **Factor of 10 improvement in  $^{199}\text{Hg}$  is just around the corner (must open the box carefully!)**

Clark Griffith

- **ILL neutron cryoEDM is well on its way**  
(too busy to come to workshop!)

- **PSI EDM is making solid progress with a strong plan in 3 phases**

Klaus Kirch

- Previous Schiff Moment approximations need to be re-evaluated

Cheng-Pang Liu tells us:

1. factorization probably not correct:

$$\left\langle d_{nuc} \otimes r^2 \right\rangle \neq \left\langle d_{nuc} \right\rangle \otimes \left\langle r^2 \right\rangle$$

Actual Operator                      Conventional approx.

2. There are additional terms:

$$\left[ Y_2 \otimes d \right]_1 \text{ must be included}$$

3. Density-density correlations can be important

Leads to 3 x larger Schiff moment in deuteron  
 May lead to modified moments for heavy nuclei

- Skyrme forces are a headache
  - Joao de Jesus
- A  $\bar{\theta}_{QCD} < 10^{-10}$  is more natural than an Axion in QCD
- Twisted Split Fermions make “big” EDMs (but not too big) and a happy flavor sector
  - Matthew Schwartz
- Single-Spin Asymmetries in HERMES can be discussed at same meeting as EDMs
  - Susan Gardner

My favorite pseudo T-odd observable

- Two-loop EDMs fit in well with schizophrenic SUSY (SSUSY)

We-Fu Chang

- Lattice QCD EDMs are now being calculated like they are measured:

Method A – Evaluate form factor and try to evolve to  $Q^2 \rightarrow 0$  - Probably not workable

Method B – Evaluate the energy of the system in an electric field as we flip the spins

**Just like the experimenters!!!**

Yoshinobu Kuramashi

- Evidence for a 1<sup>st</sup> order Electroweak phase transition in the early universe (required for EW baryogenesis) may be visible in gravitational waves

Stefano Profumo

- T-odd polarizabilities may be observable in diamagnetic systems via an E-field induced magnetic moment

Andrei Derevianko

- emiT has identified an important systematic and is close to a  $10^{-4}$  result

Pieter Mumm

- R-coefficient has new result!  $R < 0.035$

Kazimierz Bodek

# Where are we? ...

## Where are we going??

- Perhaps we are caught up in the TeV hype but...
- We appear to be at a “phase transition” in CP violation & EDMs
  - Theoretical advances are significant and critical (atomic and nuclear calcs, SUSY estimates, relation to baryogenesis)



# What's in SUSY?

- Great Names:

- Squarks, sleptons, gauginos, winos, binos, neutralinos,...

- In MSSM

- 124 parameters - 19 from Standard Model & 105 new parameters (from SUSY and also from SUSY breaking)

- 36 mixing angles for squarks & sleptons
    - 40 CP-violating phases for squarks & sleptons
    - 21 squark & slepton masses
    - 5 couplings and 3 phases from gauginos/higgsinos

# Supersymmetry

## The Standard Model of Particle Interactions

Three Generations of Matter

	I	II	III	
Quarks	$u$	$c$	$t$	$\gamma$
	$d$	$s$	$b$	
Leptons	$\nu_e$	$\nu_\mu$	$\nu_\tau$	$Z$
	$e$	$\mu$	$\tau$	

## The Minimal Supersymmetric Extension of the Standard Model (MSSM)

	I	II	III	
Squarks	$\tilde{u}$	$\tilde{c}$	$\tilde{t}$	$\tilde{\gamma}$
	$\tilde{d}$	$\tilde{s}$	$\tilde{b}$	
Sleptons	$\tilde{\nu}_e$	$\tilde{\nu}_\mu$	$\tilde{\nu}_\tau$	$\tilde{Z}$
	$\tilde{e}$	$\tilde{\mu}$	$\tilde{\tau}$	

- Experimental situation is verging on a renaissance
  - exciting opportunities in well-studied systems  
 $^{199}\text{Hg}$  and neutron
    - But major advances are challenging
  - Promising ideas in heavy atoms and solid-state systems
    - New systems have new systematics!

# Experimental EDMs

- Present best limits come from atomic systems and the free neutron
  - Paramagnetic atoms (e.g.  $^{205}\text{Tl}$ ) are primarily sensitive to  $d_e$
  - Diamagnetic atoms (e.g.  $^{199}\text{Hg}$ ) and the free neutron are primarily sensitive to  $\theta_{\text{QCD}}, d_q, \tilde{d}_q$
- Future best limits may come from
  - Molecules ( $\text{PbO}, \text{YbF}$ )
  - Liquids ( $^{129}\text{Xe}$ )
  - Solid State systems (Gadolinium-Gallium-Garnet=GGG)
  - Storage Rings (Muons, Deuteron)
  - Radioactive Atoms ( $^{225}\text{Ra}, ^{223}\text{Rn}$ )
  - New Technology for Free Neutrons (PSI, ILL, SNS)

# EDM Measurements

particle	Present Limit (90% CL) (e-cm)	Laboratory	Possible Sensitivity (e-cm)	Standard Model (e-cm)
e <sup>-</sup> (TI)	$1.6 \times 10^{-27}$	Berkeley	$10^{-29}$	$<10^{-40}$
e <sup>-</sup> (PbO)		Yale		
e <sup>-</sup> (YbF)		Sussex		
e <sup>-</sup> (GGG)		LANL/Indiana		
$\mu$	$9.3 \times 10^{-19}$	CERN	$<10^{-24}$	$<10^{-36}$
$\mu$		BNL		
n	$3 \times 10^{-26}$	ILL	$2 \times 10^{-28}$	$\sim 10^{-32}$
n		ILL		
n		PSI		
n		SNS		
<sup>199</sup> Hg	$1.9 \times 10^{-27}$	Seattle	$2 \times 10^{-28}$	$\sim 10^{-33}$
<sup>129</sup> Xe		Princeton	$10^{-31}$	$\sim 10^{-34}$
<sup>225</sup> Ra		Argonne	$10^{-28}$	
<sup>223</sup> Rn		TRIUMF	$1 \times 10^{-28}$	
d		COSY/JPARC?	$<10^{-28}$	

# INT Workshop (2012)

## CP violation and EDMs

### Top 10 predictions for the next workshop

10. Theorists predict EDMs factor of 10 lower than present best limits
9. New sources of CP violation in EDMs are tantalizing
  - $^{199}\text{Hg}$  reaches ultimate sensitivity (Norval has another good idea and reaches  $10^{-30}$  e-cm)
  - ILL and PSI reach few  $\times 10^{-27}$  e-cm for neutron
8. LHC's suggestion of new physics is confusing but definitive

7. ILC is still a gleam in the particle physics community's eye
6. Atomic systems capitalize on the latest technological developments
5. SNS EDM has next-to-last DOE review
4. Solid-State systems identify several surprising systematic effects

3. Lattice QCD completes calculation of  $d_n/\theta_{\text{QCD}}$  & begins calculation of  $d_n(d_q)$
2. Theorists predict new large enhancements ( $> 10^4$ ) in very rare isotopes (more support for 0.5B\$ FRIB)
1. EDM searches continue to offer considerable hope in clarifying the new physics



# Conclusions

- Thanks to all for making this an exciting, thought-provoking workshop !
- Expect everyone to come back in five years with exciting new results (maybe even with new ~~CR~~)