Lattice field theory - a UK perspective

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PPAP town meeting
September 2012
Applications of Lattice QCD/Lattice field theory

Particle physics
- QCD parameters
- Hadron spectrum
- Hadron structure
- CKM elements
- Theories beyond the Standard Model
- Quantum gravity

Nuclear physics
- Glueballs and exotica
- QCD at high temperatures and densities
- Nuclear masses and properties

Astrophysics

Annual proceedings of lattice conference: http://pos.sissa.it/

condensed matter physics
computational physics
computer science ...
Lattice QCD = fully nonperturbative QCD calculation

RECIPE

• Generate sets of gluon fields for Monte Carlo integrn of Path Integral (inc effect of u, d, s, (c) sea quarks)
• Calculate valence quark propagators to give “hadron correlators”
• Fit for masses and matrix elements
• Determine $a$ and fix $m_q$ to get results in physical units.
• extrapolate to $a = 0, m_{u,d} = \text{phys}$ for real world
• cost increases as $a \to 0, m_l \to \text{phys}$ and with statistics, volume.
Lattice QCD hadron physics

- \( \tau \)-decays
- Lattice
- DIS
- e\(^+\)e\(^-\) annihilation
- Z pole fits

\[ \alpha_s(M_Z) \]

\begin{tabular}{|c|c|c|}
\hline
M \text{ GeV} & 1 \ & 2 \ & 3 \ & 4 \ & 5 \ & 6 \ & 7 \\
\hline
\end{tabular}

- \( m_s \) 93.4 \( \pm \) 1.1 MeV

- lattice QCD most accurate method

- glueball masses
Precision electroweak MEs

Proton structure

$\langle x \rangle (u - d)$

SM rates for hadronic EW processes need lattice QCD ....

Muon $g-2$
Lattice QCD at high temperature, density

Temperature T [MeV]

Early universe
Higgs, LHC
RHIC
FAIR SIS-300
Quarks and Gluons
Critical point?
Deconfinement and chiral transition
Hadrons
Neutron stars
Color Superconductor?

Net Baryon Density

2-color QCD at high density

Upsilon melts at high T

\( T_c \) (MeV)

Transition is a Crossover at physical quark masses

\( \langle qq \rangle/\mu^2 \)
Polyakov line
Polyakov (a=0.23fm)

\( \rho(\omega)/M^2 \)

\( \chi_{\bar{\psi}\psi} \)

Glasgow, September 2011

Sunday, 16 September 2012
search for viable ‘walking technicolour’ theory

supersymmetry on lattice

large number of colours

limit
Future (with increased computing power)..

- lattices with physically light up and down quarks in the sea now becoming available - no chiral extrapolation!
- very fine lattices \((a<0.03 \text{ fm})\) allow b quarks to be treated relativistically rather than with effective theories
- large volumes (6 fm across) allow study of hadron resonances/multi-hadron states/small nuclei
- very high statistics give access to calculations with more intrinsic noise - flavour singlets, glueball spectrum etc
- finite temperature QCD calculations can be extended to different quark formalisms.
- the huge space of BSM theories can be explored
- not all progress requires improved computational resources but it helps!

- results for: LHC, BES, KEK, JLAB, DAFNE, RHIC, FAIR ...
UK landscape - people

UK provides ~8% of worldwide lattice community.

20% of top-cited papers from hep-lat have at least one UK author¹

• judged from attendance at the annual lattice QCD conference

¹ from SPIRES, sampling years 2005-2010

8 universities form UKQCD consortium = ~ 50 people. Members of international collaborations such as: e.g ETM, HPQCD, QCDSF, RBC-UKQCD, strongBSM
UK landscape - computing

STFC’s DiRAC (Distributed Research using Advanced Computing) facility started in 2009 with £13M LFCF grant.

Aim to provide HPC needs of theoretical particle physics along with astrophysics/cosmology.

8 science consortia (UKQCD consortium + 7 astro) funded under phase 1 - computers at 13 sites.

Phase 2 (2012-15) now operating - £15M capital from BIS plus £1.7M STFC ops (only pays electricity for one year).

5 machines at 4 sites (Cambridge, Durham, Edinburgh and Leicester)- coordinated management and peer-reviewed resource allocation (starting Dec. 2012) open to all
Lattice field theory researchers focussed on two machines:
1) 6-rack BG/Q at Edinburgh. DiRAC 1+2 ~ £10M (inc. discount from Ed-IBM collaboration on hardware).
20 in top 500* - 1Pflops
2) Sandybridge/infiniband cluster at Cambridge. DiRAC 2 ~£1.5M for half machine.
93 in top 500* - 200 Tflops (total machine).

These machines give new capabilities e.g. results now obtained at physically light up/down quark masses.

B decay constant: R. Dowdall (Glasgow, HPQCD) in progress on Cambridge cluster

* www.top500.org : Hartree centre 13; HecTor 32.
Future needs/plans (for whole of DiRAC)

• Top priority is for funding for electricity costs of £1M per year from August 2013.

• Increase in support staff (currently 4) to 8 plus additional code development support (of 4) would improve uptime and efficiency. Aim to tackle some technical issues e.g. authentication, data handling, code efficiency, hardware in collaboration with others (industry, GRIDPP ..).

• Increase in PDRAs (+3 per year on pre-2011 number) + PhDs (+10 per year) in particle theory would improve exploitation capabilities.

• 2014-15 - DiRAC phase 3 - seeking £35M from BIS for 20X performance upgrade. Associated support costs needed