Lattice field theory - a European perspective

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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

lattice QCD most accurate method

$
\begin{align*}
\alpha_s(M_Z) & \quad 0.11 \quad 0.12 \quad 0.13 \\
M[\text{MeV}] & \quad 0 \quad 500 \quad 1000 \quad 1500 \quad 2000 \\
\end{align*}
$

$M - M_{\pi}$ (MeV)

$M_s$ = 93.4 ± 1.1 MeV

excited charmonium spectrum with hybrids

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Precision electroweak MEs

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

muon g-2

WIMP-nucleon scattering...
Lattice QCD at high temperature, density

Transition is a CROSSOVER at physical quark masses

Equation of state

melting of Upsilon states

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search for viable ‘walking technicolour’ theory

supersymmetry on lattice

large number of colours limit

Beyond QCD ..

Lattice quantum gravity

Concluding remarks

Spectral Dimension

Recent results

Confining flux tubes behave as Nambu-Goto strings

Glueball masses have a smooth dependence on

The equation of state depends only trivially on

The continuum twist of

The supersymmetric invariance of this term then relies on th

The lattice field strength is then given by the gauged forward

This use of forward and backward di

much like in 4D:

The gauge fields are realized

The components of a complexified five dimensional gauge fiel

The dimensional reduction of a five

The field strength operator guarant

The integral is

The covariant derivative is

The gauge symmetries are realized

The additional fermion degeneracy is already required by th

The equation of motion for the K"ahler-Dirac fermion is

The action of this theory contains a

The K"ahler-Dirac field in the corresponding number of dimensio

In four dimensions the constraint that the target theory pos

by introducing a lattice with half the lattice spacing one can

problems are evaded [19]. Indeed, by introducing a lattice w

much less of the perturbative sectors. In particular, the pre

Marcus twist requires a new

The lattice twist provides a particularly simple realization

The fundamental fermion action is given by

This action is convenient because it allows one to calculate

The action given in eqn. 6 provided one extends the field labels to

Many other examples of supersymmetric lattices exist. Figure

Figure 2. shows two such lattices
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 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 ...
European landscape - people

Many European countries active in lattice field theory*:

Europe provides ~50% of worldwide lattice community• of a few thousand.

70% of top-cited papers from hep-lat have some European authors^

• judged from attendance at the annual lattice QCD conference

^ from SPIRES, sampling years 2005-2010

*input to this talk from almost all of them
European landscape - collaborations

Vary from international collaborations of ~20 people (e.g. Alpha, BMW, CLS, ETM, Hadron Spectrum, HotQCD, HPQCD, QCDSF, RBC-UKQCD, StrongBSM) to smaller groups. Sociologically tricky for theorists, but necessary for access to computing resources.

Significant fragmentation of European community around different discretisations of QCD Lagrangian. Good for diversity or inefficient?

Some success at bringing people together with EU networks - currently StrongNET and participation in III Hadronphysics 3. Flavianet spun out FLAG (lattice averaging group).
European landscape - computing

Europe has 7 of world’s top 20 computers* with Pflops speed (32 of top 100 vs USA: 37 of top 100)

Lattice QCD has some access to these capability machines, but analysis phase needs large-scale capacity computing.

Hardware is provided nationally and piecemeal but PRACE provides important Europe-wide access

* www.top500.org

BUT

fundamental physics not a top priority ...

Lattice QCD not chosen as an application area for the EXASCALE DEEP project

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International Lattice DataGrid
Global initiative allowing gluon field configurations to be made publically available for analysis. BUT no resources available to run this ...

US DoE SciDAC initiative
Provides steady source of funds for computing hardware and people to develop publically available efficient parallel software for lattice calculations. Smaller European groups use this - would be good to contribute/have our own initiative BUT no resources for this ...

Lattice QCD pushes boundary of supercomputer “grand challenges” (and has led to hardware developments) so is a good technical training environment.
Conclusions

Europe must maintain a long-term world-leading programme in lattice gauge theory both as vital input for the experimental programme and for the leading-edge technology skills base.

This requires sustained investment in computing infrastructure, support and people. To be competitive, we need 10-20M€ per year for dedicated hardware + 4M€ per year for software/algorithm development across Europe. More coordination between researchers would help us argue for this investment and maximise the output from it in research, training and communication of results. We need mechanisms within Europe to encourage this to happen.