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INFN - Roma Tre

SUMA Workshop on
Supermassive Calculations in Theoretical Physics
FBK, Trento
February 11th -13th, 2015

Lattice QCD and the phenomenology of Flavor Physics

New Physics energy scale Λ_{NP} still unknown

$\Lambda_{NP} \sim 1$ TeV

direct search of NP at LHC possible
indirect search of NP complementary

$\Lambda_{NP} >> 1$ TeV

only indirect search of NP
(through virtual loop effects)

Precision studies of New Physics are an important part of existing and planned experiments

LHCb at CERN, Belle2 at KEK, NA62 at CERN, KOTO at J-PARC, MEG at PSI, ...

* the interpretation of experimental data typically requires the precise knowledge of hadronic parameters

* lattice QCD is capable to encode all the non-perturbative effects of the strong interactions starting from first principles

the goal is to achieve a theoretical precision comparable to the experimental one

Flavor Lattice Averaging Group

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THE EUROPEAN PHYSICAL JOURNAL C

Review

Review of lattice results concerning low-energy particle physics

FLAG Working Group

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The aim of FLAG is to answer the question:

" What is currently the best lattice value for a particular quantity ? "

FLAG-1 review in 2011
FLAG-2 review in 2014

FLAG-3 review in progress

quantity	FLAG-2 average	FLAG-2 error (%)	relevance	"expected" error (%)
$\alpha_{\overline{MS}}^{(5)}(M_Z)$	0.1184 (12)	1.0	QCD parameter	~ 0.5
m_{ud} (MeV)	3.42 (9)	2.6	QCD parameter	OK (=> ~ 1)
m_s (MeV)	93.8 (2.4)	2.6	QCD parameter	OK (=> ~ 1)
f_{K^+}/f_{π^+}	1.195 (5)	0.4	V_{us} from $K_{\ell 2}$	~ 0.2
$f_+^{K\pi}(0)$	0.9661 (32)	0.3	V_{us} from $K_{\ell 3}$	~ 0.2
$\hat{B}_K$	0.766 (10)	1.3	$K-\overline{K}$ oscillations	~ 0.1
f_{D_s} (MeV)	248.6 (2.7)	1.1	V_{cs} (V_{cd})	~ 0.2
f_{B_s} (MeV)	224 (5)	2.2	$B_s \to \mu^+\mu^-$	~ 0.5
$f_{B_s}\sqrt{\hat{B}_{B_s}}$ (MeV)	266 (18)	6.8	$B-\overline{B}$ oscillations	~ 1
ξ	1.268 (63)	5.0	$B-\overline{B}$ oscillations	~ 1

In addition:

* the (vector and scalar) form factors for the semileptonic decays $D \to \pi(K)\ell\nu_\ell$ relevant for V_{cd}

and **more challenging** the form factors for the semileptonic decays $B \to \pi(K,D)\ell\nu_\ell$ relevant for V_{ub} (V_{cb})

- the physical b-quark cannot be simulated on present lattices

- ETMC has developed the **"ratio method"** to deal with the extrapolation from the physical charm to the physical beauty quark

Blossier et al., JHEP 04 (2010)
Dimopoulos et al., JHEP 01 (2012)
Carrasco et al., JHEP 03 (2014)

- the computation of form factors is demanding for the memory requirements: $V*T = (48)^3 * 96$, 10 heavy quark masses from the c- to the b-quark, 10 values of injected quark momenta (via non-periodic boundary conditions), 2 stochastic sources per gauge conf. ===> ~ 800 propagators of ~ 16 GB each

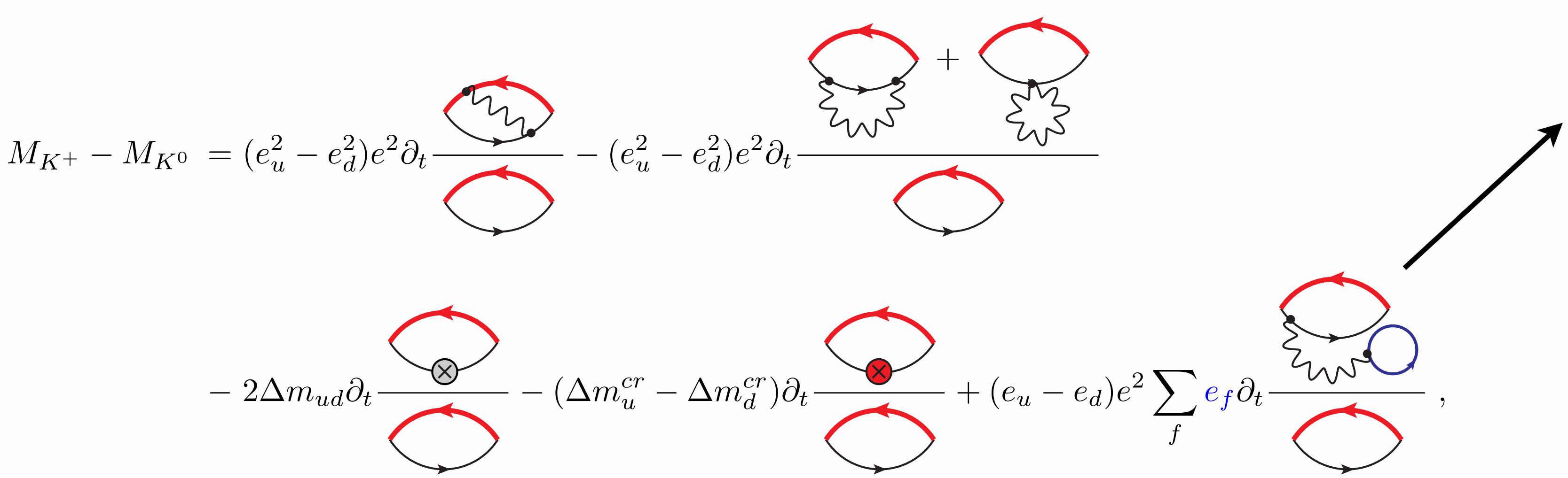
~ 13 TB of memory ===> ~ 800 nodes of BG/Q or ~ 100 nodes of Galileo

* Isospin Breaking (IB) effects due to the up/down quark mass difference and electric charges

- RM123 group has developed a new, efficient method to evaluate IB effects on hadron masses (infrared divergency free) and on decay rates

de Divitiis et al., JHEP 04 (2012)
PRD87 (2013)
Carrasco et al., arXiv: 1502.00257

- need of evaluating (fermionic) disconnected diagrams to overcome the quenched QED approximation



$Tr\{\Gamma S(x,x)\}$

computation demanding:

inversions on hundreds of stochastic sources per gauge configuration

ROMA TRE UNIVERSITÀ DEGLI STUDI

INFN Istituto Nazionale di Fisica Nucleare

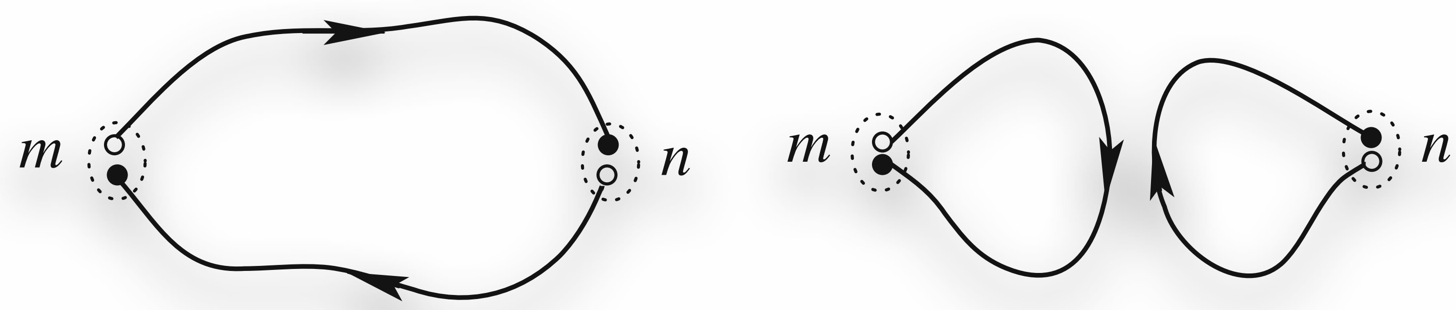
Adopting modern hardware for lattice QCD calculations

Mario Schröck

SUMA Meeting

Trento, February 12, 2015

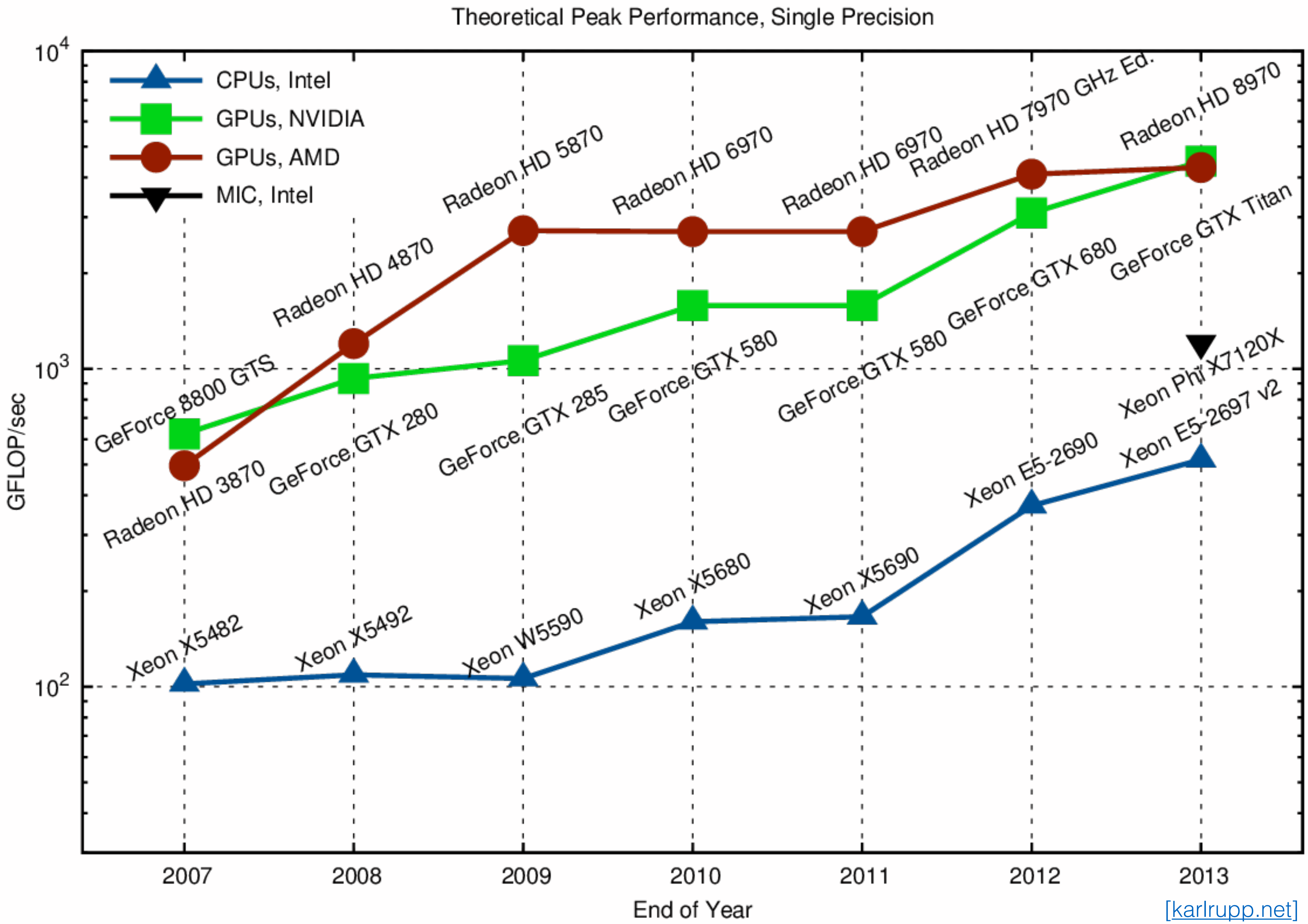
Motivation



- inclusion of disconnected quark loops in lattice QCD requires *ab initio* the complete inversion of a rank ≳ one million matrix
- clever algorithms lower this to 100-1000 solutions per gauge field configuration
- costs of the inversions still highly dominate the post gauge field generation analysis

⇒ adopt modern hardware to accelerate the inversions!

Hardware comparison



[karlrupp.net]

LQCD on GPUs

LQCD GPU libs

QUDA

- "QCD on CUDA" `http://lattice.github.com/quda`
- Effort started at Boston University in 2008, now in wide use as the GPU solver backend for Chroma, MILC, and various other codes.
- Various solvers for several discretizations, including multi-GPU support and domain-decomposed (Schwarz) preconditioners.

cuLGT

- "CUDA Lattice Gauge Theory" `http://www.cuLGT.com`
- Evolved since 2010, developed in Graz and Tübingen. [Schröck, Vogt]
- Main focus lies on lattice gauge fixing (Coulomb, Landau and maximally Abelian gauge) but a very general, object oriented infrastructure for lattice QCD calculations on GPUs is offered.

Performance

on Eurora @ Cineca: NVIDIA Tesla K20

- lattice size 32^4
- Quda: twisted mass conjugent gradient inverter (nondegenerate doublet of quark flavours)
- cuLGT: Landau gauge fixing with the overrelaxation algorithm

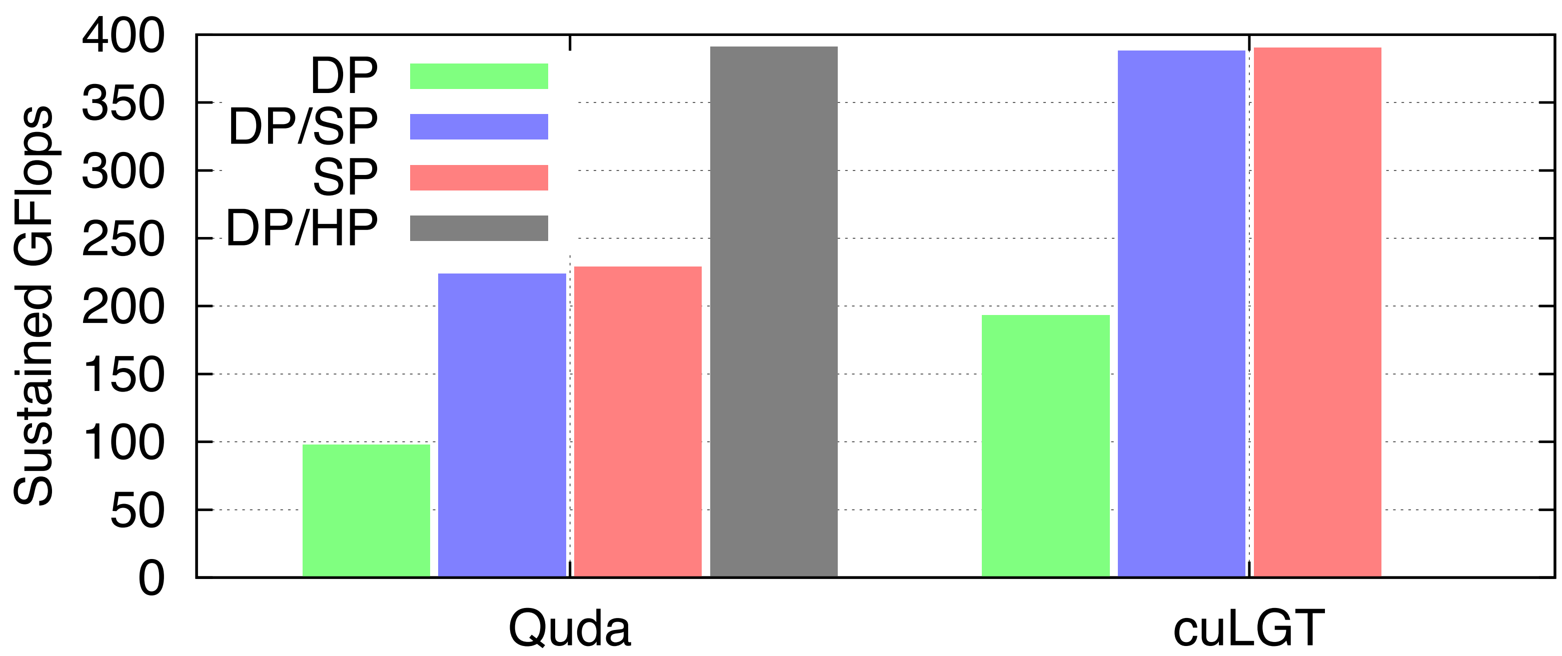


Figure 1: The different colors correspond to double precision (DP), mixed double/single precision (DP/SP), single precision (SP) and mixed double/half precision (DP/HP) (only Quda).

Comparison to previous setups

- Fermi @ Cineca: BlueGene/Q (10.240 nodes with 16 cores each)
- Processor Type: IBM PowerA2, 1.6 GHz
- setup which is in production at Roma Tre:
  - $32^3 \times 64$ lattice: twisted mass inverter with mixed double/single precision and SSE vector instructions
  - **128 Fermi nodes (2048 CPU cores)**
- compare to:
  - same lattice, equivalent inverter (Quda) with mixed double/half precision
  - **one Eurora node (two GPUs)**
- ratio of average time per inverter iteration:

$$\frac{t_{\text{Fermi}}}{t_{\text{Eurora}}} = \frac{0.009898s}{0.017016s} = 0.58$$

Multi-GPU performance

on Eurora @ Cineca: NVIDIA Tesla K20

- Quda twisted mass inverter with one flavour of quarks
- double/half mixed precision and 12 parameter reconstruction

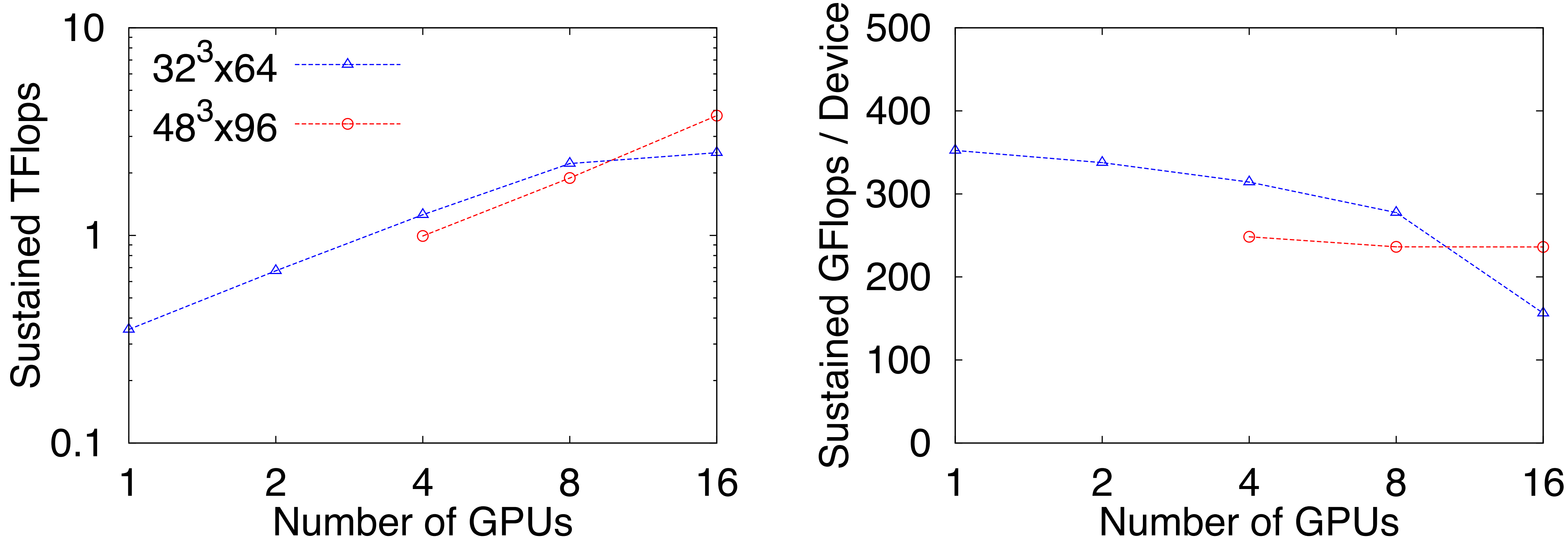


Figure 2: Strong scaling for two different lattice sizes. On the left the total performance and on the right the performance per GPU.

LQCD on Intel MICs
(outlook)

Galileo @ Cineca

516 Compute nodes:

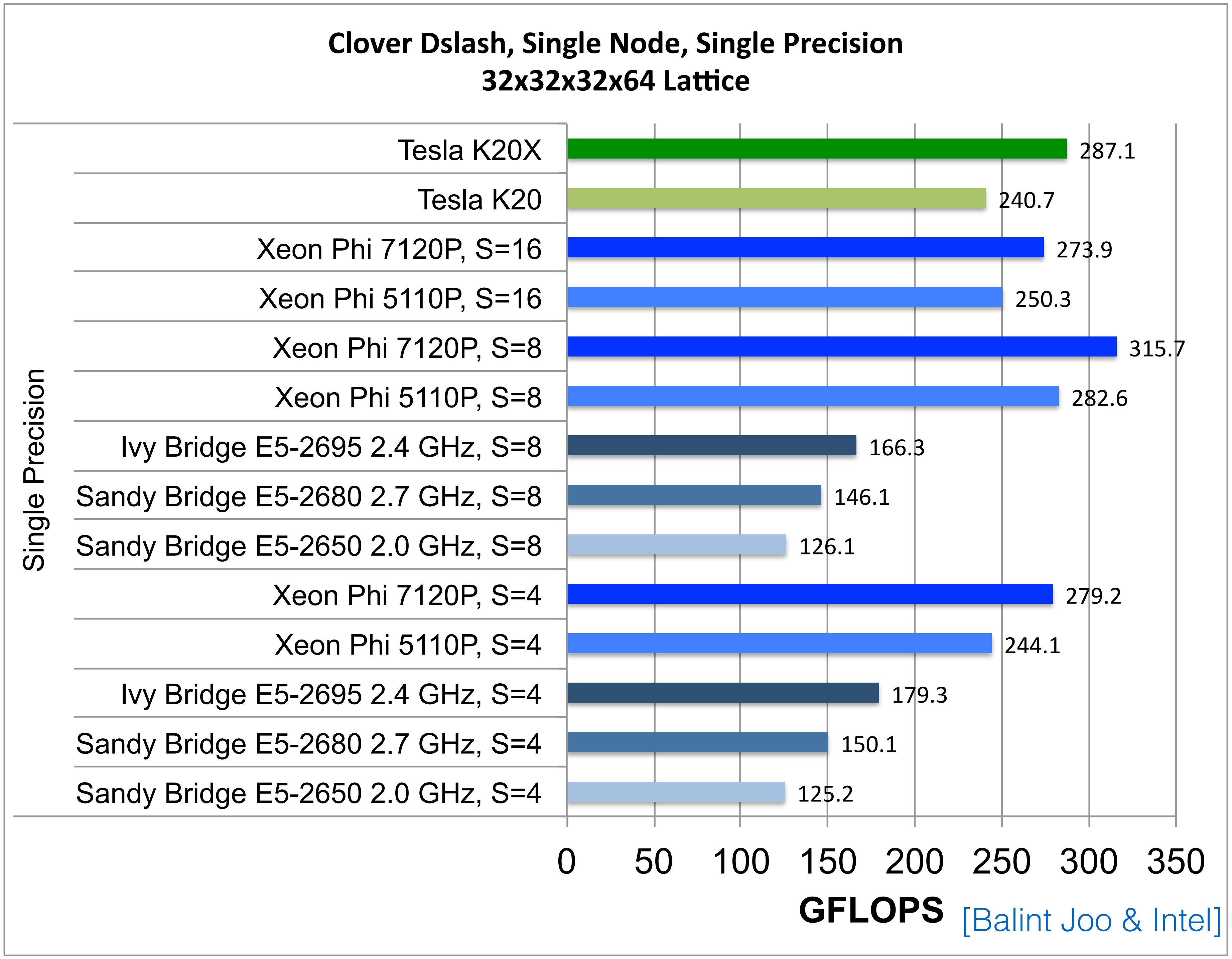
- 2 octa-core Intel(R) Xeon(R) CPU E5-2630 v3 @ 2.40GHz per Compute node
- 128 GB RAM per Compute node
- 2 x 16GB Intel Xeon-Phi 7120P Accelerator per Compute node (on 384 nodes)

LQCD MIC libs

- QPhiX Library implements
  - Wilson & Clover Dirac Operators
    - D, $A^{-1}D$ — “Dslash”
    - $A\chi - b D \psi$ — “aChiMBDPsi” -variant
    - Use these to assemble: $(1 - DD)$ or $(A - DA^{-1}D)$ Even-Odd Schur prec operators
  - Basic Solvers
    - CG, BiCGStab, Iterative Refinement (for mixed precision)
- Written in C++
  - Currently mostly geared to interfacing with QDP++/Chroma

[Balint Joo & Intel]

QPhiX performance



Summary & Outlook

- modern highly parallel hardware is very suitable to accelerate lattice QCD simulations
- with the Eurora GPU cluster we obtain the same performance as on BlueGene/Q on a drastically reduced number of nodes (i.e. reduced energy consumption)
- we are currently finishing the implementation of Twisted Mass fermions within the QPhiX lib for Intel Xeon Phi (with A. Strelchenko) in order to run on Galileo @ Cineca