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Centro Studi e Ricerche Enrico Fermi

Super-calculus and physics of strong interactions

[2/2016 - 2/2018]

Grant Holder: **Petros Dimopoulos**

Centro Fermi & Dipartimento di Fisica,
Università di Roma "Tor Vergata"

Scientific Supervisor: **Prof. Giancarlo Rossi**

FLAG
Flavour Lattice Averaging Group

UNIVERSITA' DEGLI STUDI DI ROMA
TorVergata

European Twisted Mass Collaboration

Centro Fermi, Rome, March 2, 2017

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Description of the Project

- **A twofold project**

  - Exploration of the **SM** precision limits in Flavour Physics & Search of footprints of **BSM** physics.

    Study of the hadronic (QCD) contribution to weak interaction processes in synergy with the current huge investment in experimental resources **(LHCb, Charm and B factories).**

  - Probe **new strong interaction** effects responsible for a mechanism of dynamical generation of fermion masses (unrelated to the Higgs mechanism).

Study of fundamental **non-perturbative** effects in both projects requires numerical Monte Carlo simulations on **supercomputing platforms.**

Simulations on large architectures

+

optimised parallelisation

- **BG/Q Juqueen** (Jülich) and **Fermi**-Cineca (Bologna)
- **Intel Xeon** of **Marconi-**Cineca (platforms A1, A2) and **Galileo-**Cineca
- **Intel Xeon Haswell SuperMUC**-Leibniz Supercomputing Center (Munchen)
- **BG/Q Turing** (IDRIS - CNRS)
- **algorithms**: Hybrid Monte Carlo + many tricks for acceleration

[Prace Early and 4th, 10th , 13th regular calls (2011, 2013, 2015, 2016) & Gauss Center for Supercomputing (GCS) (2014, 2016)]

Synthesis of results & publications in 2016

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B-physics & Lattice QCD

Phys.Rev. D93 (2016)

- **Lattice QCD simulations with four dynamical flavours**
- Present CPU limitations do not allow direct (reliable) simulations at m_b
- However **clever combination of lattice observables with HQET leads to optimal control of discretisation effects even at the scale of b-quark mass.**

observable	f_{Bs}	f_B	f_{Bs}/f_B	m_b	m_b/m_c	m_b/m_s
precision %	2.2	3.1	2.2	2.3	1.8	2.7

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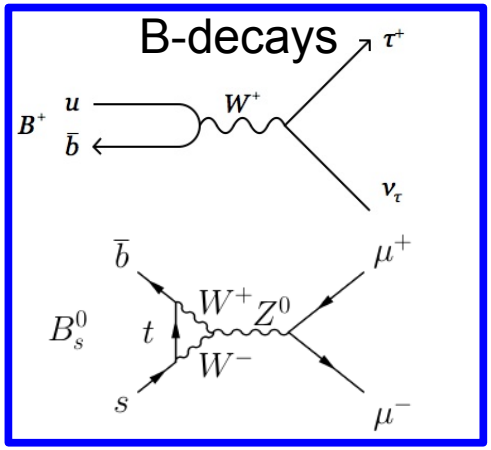

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- **High precision Lattice QCD results**
- B-meson decay constant lattice determinations are required for full interpretation of the BR of the respective decays studied in **LHCb and BelleII** (extract relevant info on CKM matrix elements). Theoretical -Lattice QCD- achieved precision is currently higher than the experimental one.
- Non-perturbative precise determinations of heavy quark masses, m_b and m_c, needed in the accurate calculation of Higgs decays in quark-antiquark pair (LHC)

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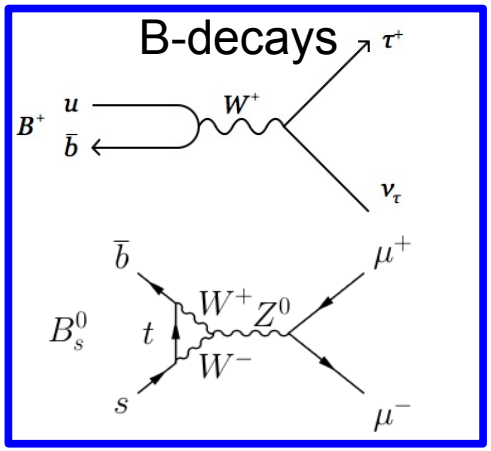

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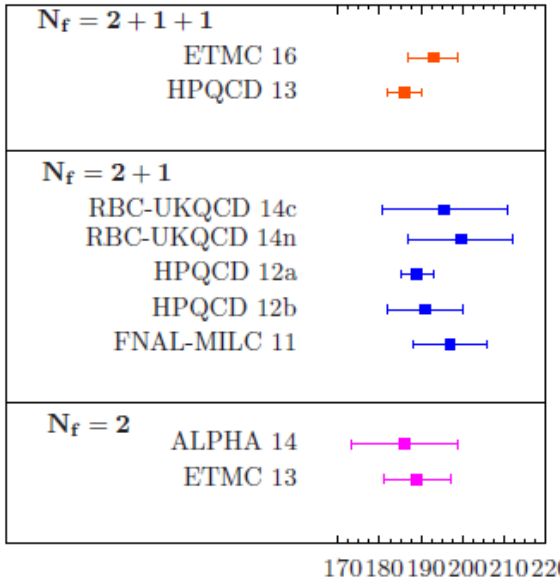
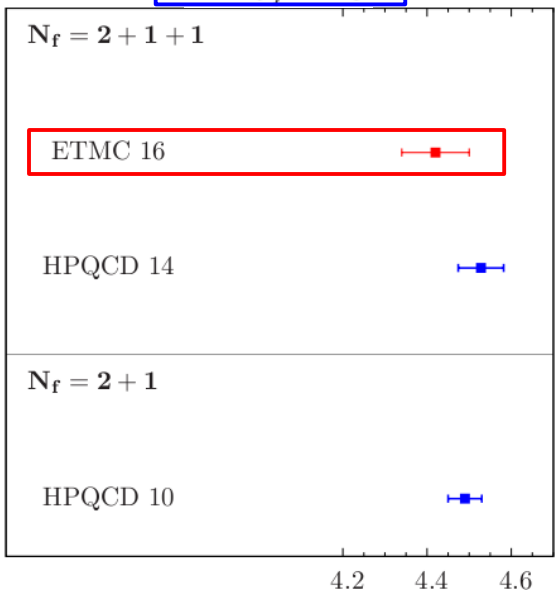
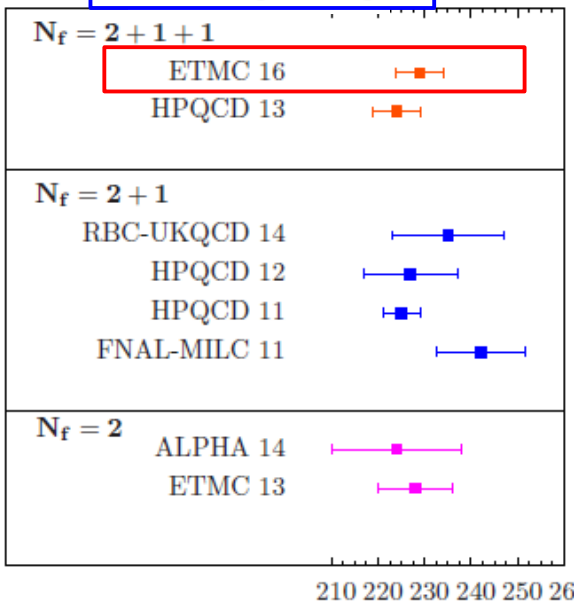
f_B [MeV]



m_b/m_c



f_{Bs} [MeV]



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LQCD simulation reproducing physical pion mass physics

Employing two and four dynamical flavours

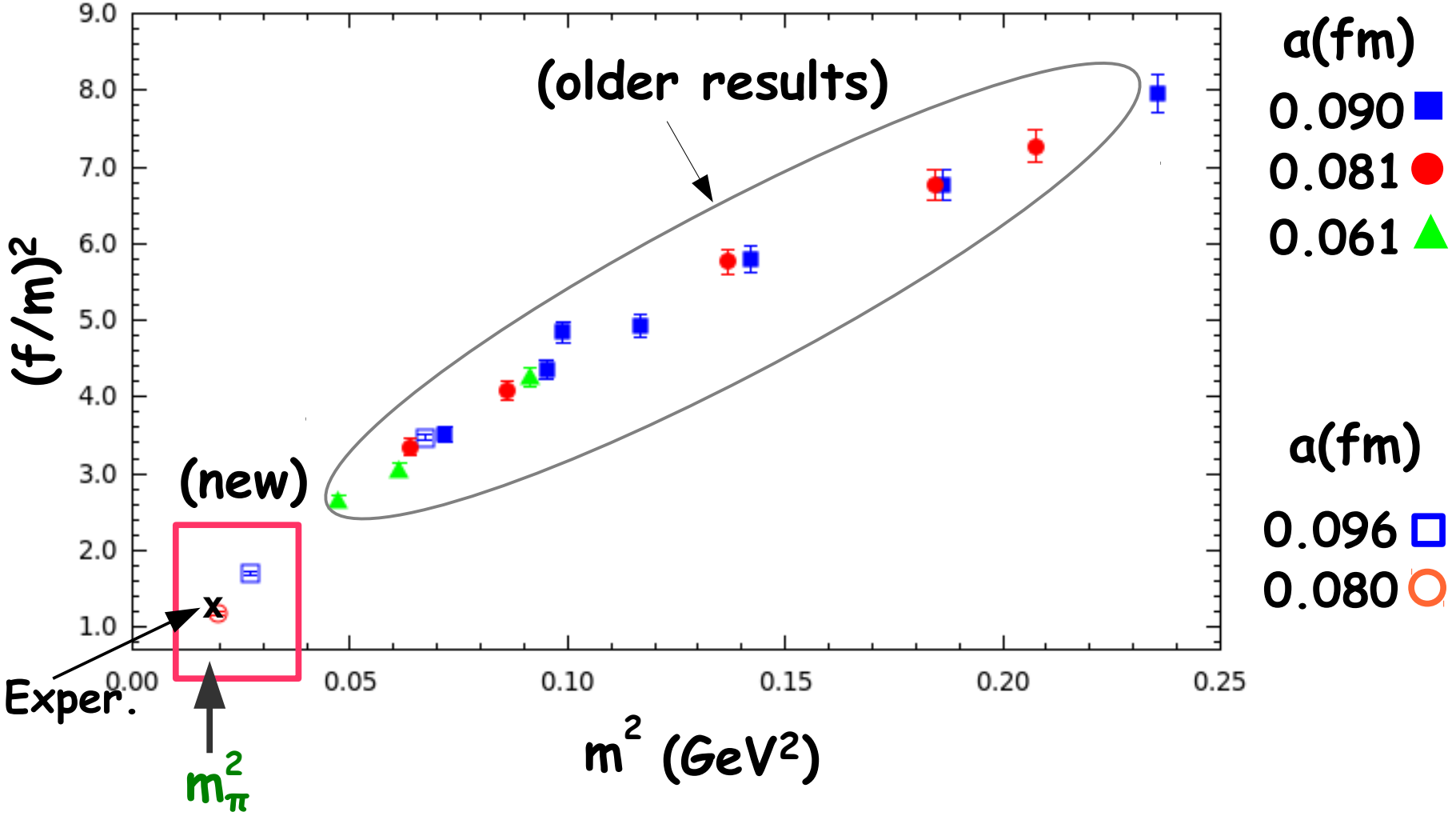
2 papers submitted to Phys.Rev. D
+ PoS LATTICE 2016

- simulations with **two physical light dynamical flavours** at one lattice spacing and on two large lattice volumes with physical dimension of 4.5 fm and 6.0 fm.

- fully realistic simulations with **two light & strange and charm dynamical flavours set as to reproduce physical π, K and D meson masses** at two lattice spacings and on large lattice volumes with physical dimension of about 5 fm.

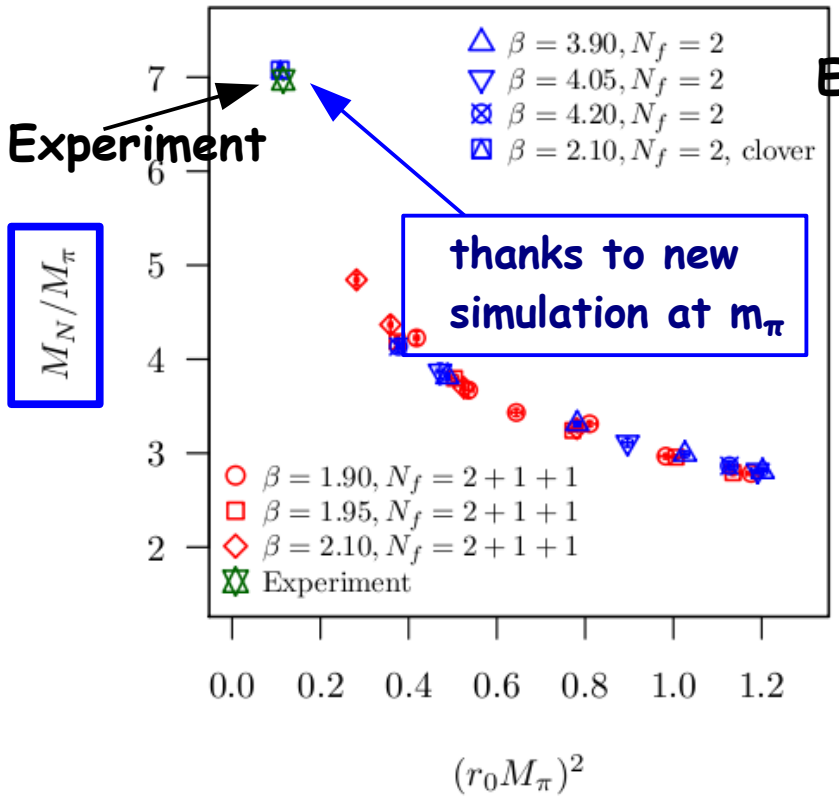
- **Challenging simulation task**:
  employ improved LQCD actions + advanced algorithms @ elevated CPU cost
- **The goal**:
  Elimination of systematic uncertainties due to chiral extrapolation.
  Employing LQCD data to check, not being guided by, ChPT arguments.

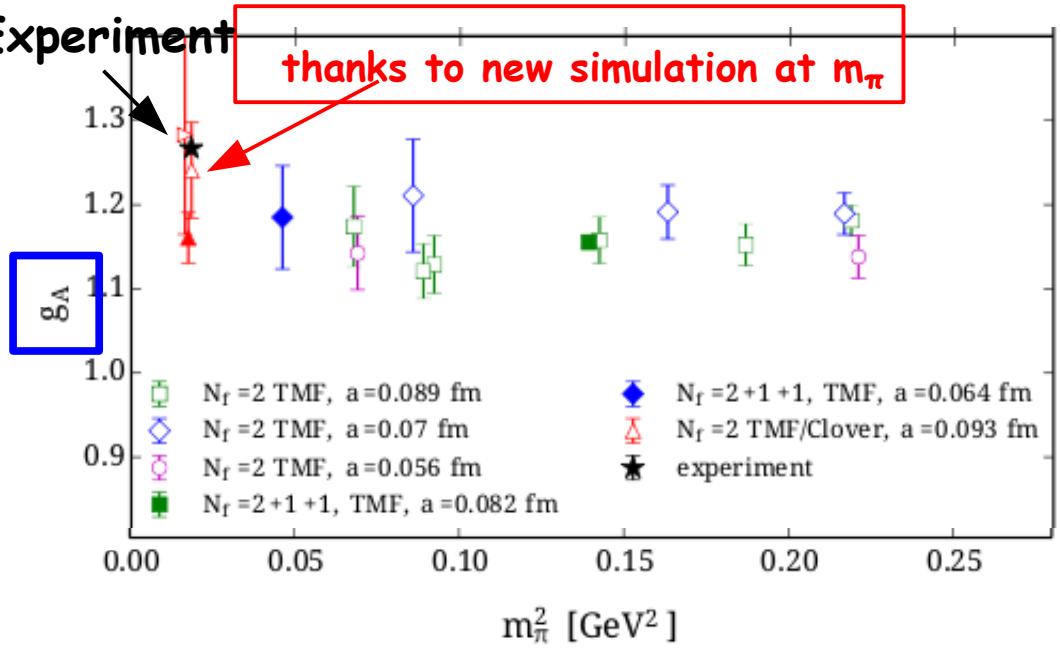
LQCD simulations with 4-dynamical quarks set at their phys. mass values compared with older simulations



(Ongoing simulations on Marconi-Cineca and SuperMUC-LSC)

LQCD simulations with 2-dynamical quarks set at their phys. mass values compared with older simulations





Crucial achievement of Lattice QCD:

physical quark lattice QCD simulations capable to achieve impressive accuracy and reproduce experimental values of imprortant physical quantities.

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Dynamical generation of elementary particle masses

PoS LATTICE 2016 (2016) 212

- **mass hierarchy problem**: deeper understanding animates BSM exploration.

- **A Novel Mechanism :**

  Frezzotti & Rossi Phys. Rev. D92 (2015)

  Mass generation seen as non-perturbative effect of SχSB phenomenon induced by an "irrelevant" chiral breaking operator ⟶
  dynamical generation of mass terms

- **Reproduce the mechanism in a toy-model tested with LQCD methods:**
  SU(Nf=2) doublet of massless strongly interacting fermions coupled to **scalar field** through Yukawa interaction while allowing (d=6) Wilson-type term.

  Numerical study on Galileo and Marconi-Cineca:
  - adjust/test lattice action setup
  - parameters tuning
  - exploratory investigation of the mechanism on one lattice spacing

⟶ **Perfectly falsifiable BSM conjecture employing lattice methods**

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Flavour Lattice Averaging Group (FLAG)

Eur.Phys.J. C77 (2017)

- **Review (covering about 400 pages) of lattice results relevant to low-energy physics and Flavour Physics Phenomenology of the SM**

FLAG collaboration comprises experts from USA, Europe and Japan in Lattice Field Theory, Chiral Perturbation Theory and Standard Model phenomenology.

➡ **Aim**: provide the most representative and reliable current determinations of a large number of QCD observables measured on the lattice.

- **Make LQCD results accessible to the particle-physics phenomenologists and experimentalists.**

- FLAG collaboration is to provide updates, in the form of a peer reviewed publication, roughly on a biennial basis.

Updates are regularly provided in the **FLAG website**

http://itpwiki.unibe.ch/ag

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Conclusions and Outlook

- High precision determinations for B-decay constants and b-quark mass.
- Generation of LQCD simulations at the physical value of quark masses at three different lattice spacings and on several lattice volumes. First physics results relevant for the SM phenomenology.

  A big and challenging project in progress comprising optimised algorithms, realisation of high CPU-cost LQCD simulations. Extension to large statistics targeting reduced uncertainties for physical observable determinations in the π, K and D region (2017).
- Numerical study of the dynamical generation mechanism of elementary fermion masses. This study will allow to prove (or disprove) the occurrence of the conjectured non-perturbative fermion mass generation phenomenon.
- Publication of an extended critical Review presenting world LQCD results. Provide representative summaries of results (and regular updates) for use from the particle phenomenology community.

Links to other Projects

- European Twisted Mass Collaboration: Fully realistic LQCD simulations
- ROM123 initiative: lattice QCD simulations with isospin breaking and EM effects
- Project LIBETOV: leading isospin breaking effects from Lattice QCD + QED (expired 2016)
- Collaboration with Bonn / Barcelona theory groups on the project concerning dynamical mass generation"
- FLAG collaboration: provide review and world lattice averages required in particle physics phenomenology
- Prace, regular call 2016; Gauss Center of Supercomputing (2016)

Synthesis of research impact

- Joint effort between LQCD theoretical computations and experimental measurements for improving the SM precision in the flavour sector.
- Various observable determinations by ETMC included in PDG and employed by the high energy community working in SM phenomenology and BSM models.
- Compilation and critical review of world LQCD results by FLAG Collaboration for use by the particle phenomenology community.

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Publications in 2016

[1] A. Bussone, N. Carrasco, P. Dimopoulos, R. Frezzotti, *et al.* [ETM Collaboration], "*Mass of the b quark and B -meson decay constants from N_f=2+1+1 twisted-mass lattice QCD*," Phys. Rev. D **93** (2016) no.11, 114505 doi:10.1103/PhysRevD.93.114505

[2] S. Aoki *et al.*, Eur. Phys. J. C **77** (2017) no.2, 112 doi:10.1140/epjc/s10052-016-4509-7

[3] A. Abdel-Rehim, C. Alexandrou, F. Burger, M. Constantinou, P. Dimopoulos *et al.* [ETM Collaboration], "*Simulating QCD at the Physical Point with N_f = 2 Wilson Twisted Mass Fermions at Maximal Twist*," (submitted to Phys. Rev. D)

[4] S. Capitani, GM De Divitiis, P. Dimopoulos, R. Frezzotti, *et al.*, "*Check of a new non-perturbative mechanism for elementary fermion mass generation*," PoS LATTICE **2016** (2016) 212

[5] L. Liu, S. Bacchio, P. Dimopoulos, J. Finkenrath *et al.*, [ETM Collaboration] "*Isospin-0 $\pi\pi$ s-wave scattering length from twisted mass lattice QCD*," (submitted to Phys. Rev. D)

[6] L. Liu, S. Bacchio, P. Dimopoulos, J. Finkenrath *et al.*, [ETM Collaboration] "*Isospin-0 $\pi\pi$ scattering from twisted mass lattice QCD*," PoS LATTICE**2016**

Thank you for your attention