Field Theory Simulation towards Fugaku

Yasumichi Aoki (Field Theory Research Team)

17, February 2020
2nd R-CCS Inernational Symposium

Quantum Field Theory

- Quantum mechanics: physics framework for microscopic world
- Special Relativity: physics framework of fast moving particle

- Quantum Field Theory (QFT)

- Standard Model of Particle Physics : most successful application of QFT

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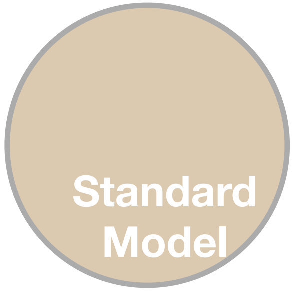
Standard Model
- Electromagnetism
- Weak Interaction
- QCD



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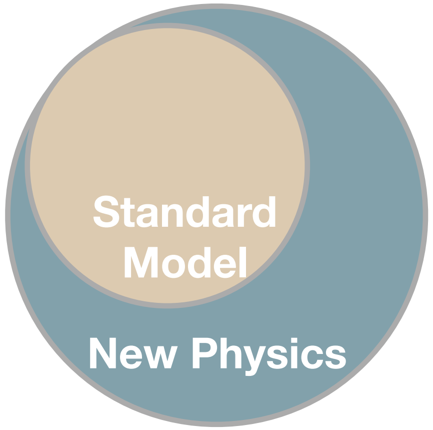

- Test of the Standard Model
- Seeking physics beyond the Standard Model for “New” Physics

are central targets of particle physics

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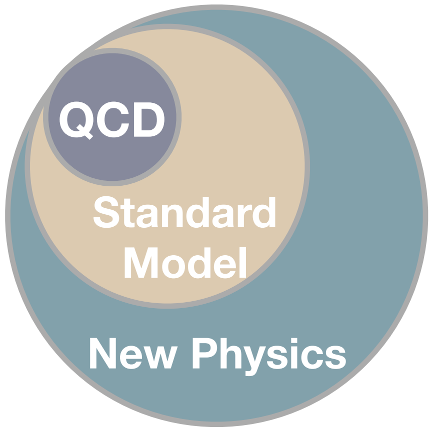

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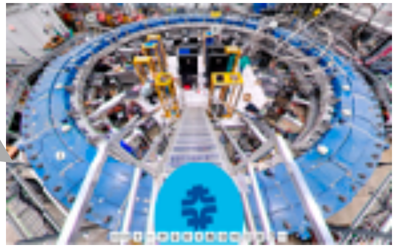
are central targets of particle physics

- QCD has most complex dynamics → numerical simulation is most powerful tool

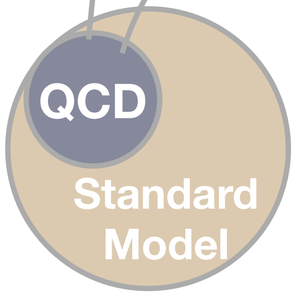
Fermilab
/ J-Parc

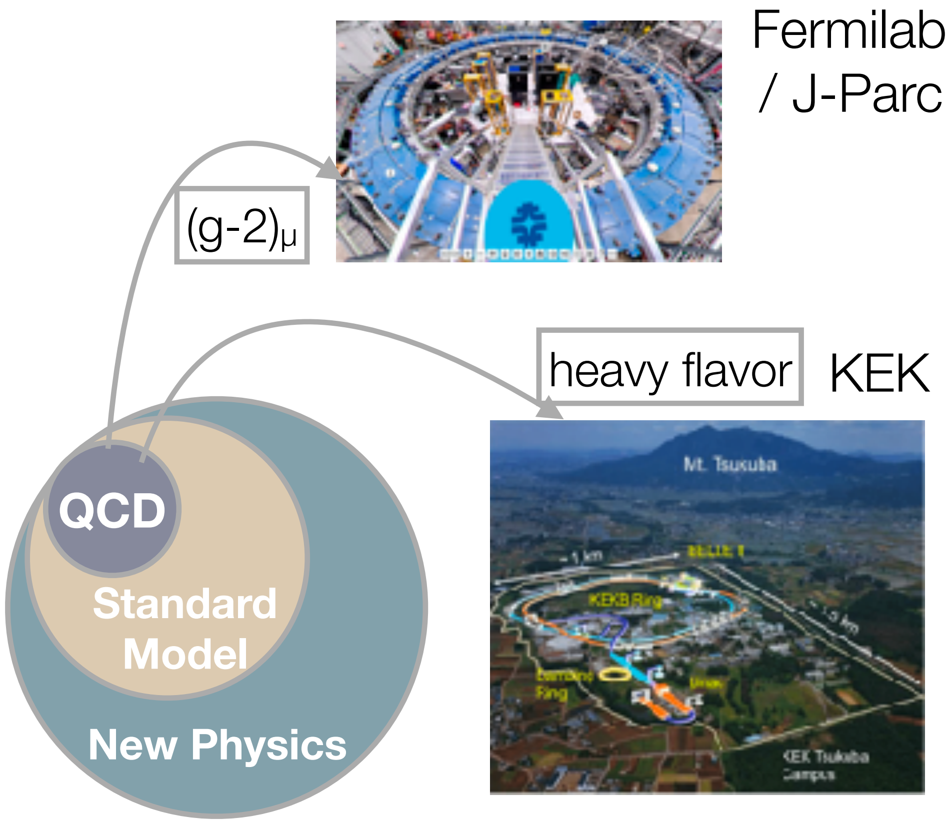
$(g-2)_\mu$



heavy flavor

KEK




Fermilab
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(g-2)μ
heavy flavor
KEK
Mt. Tsukuba
QCD
Standard
Model
New Physics

heavy flavor

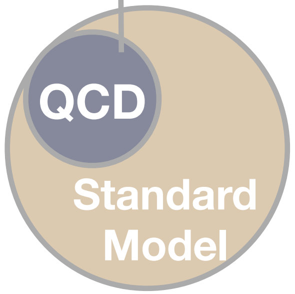
Compute

=

?

≠

Measure



KEK

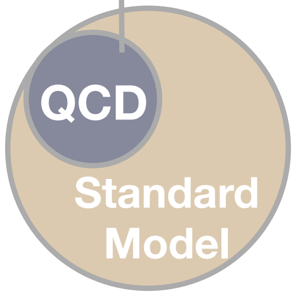
heavy flavor

reality is much complicated

Compute (V_{ij}) = Measure

Constrains parameters in Standard Model

Kobayashi-Maskawa matrix elements V_{ij}



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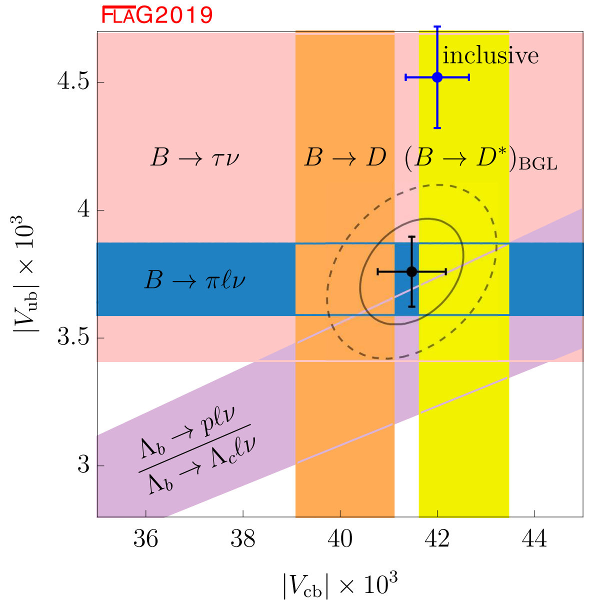
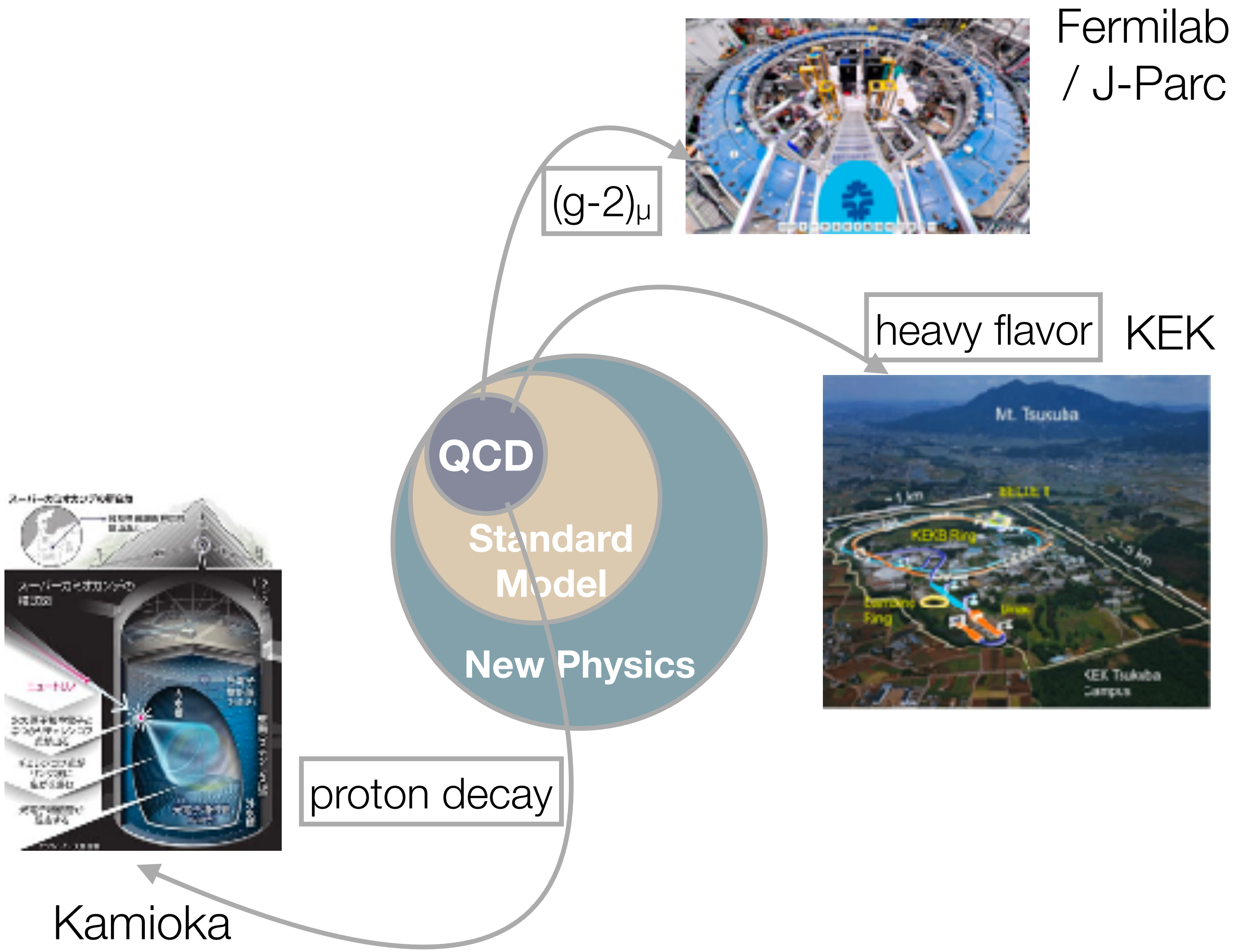


Q: consistency btw many different processes ?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proton decay
Kamioka

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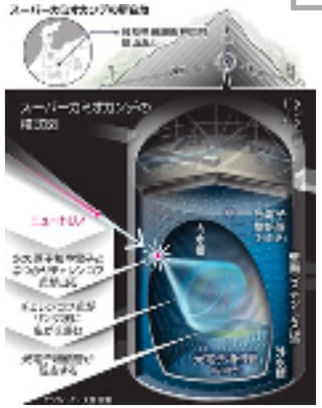

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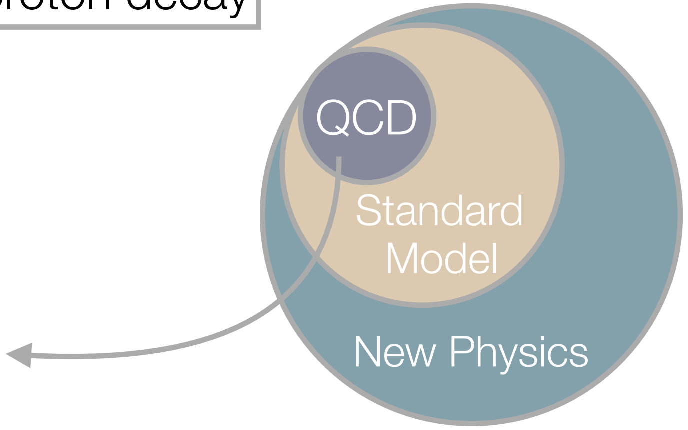


QCD for the tool to bridge new physics

proton decay matrix element as an example

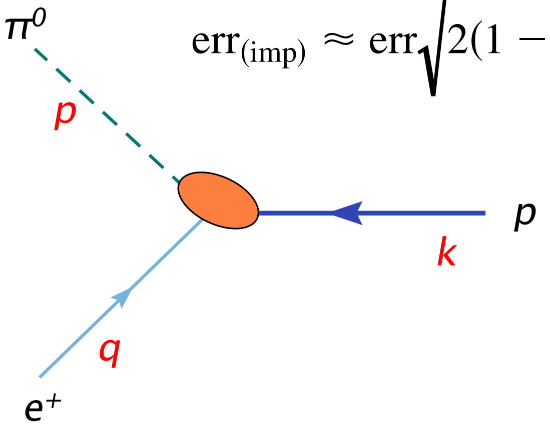
- bridge between new theories and experiments

  (GUTs) (SuperKamiokande etc)

non-chiral fermions used for a test

- chiral extrapolation : largest systematic uncertainty
- physical point simulation will solve this completely
- small mass, large volume (64^4, 96^4) required
- All mode averaging (**AMA**) with many sloppy linear solv
  - correlation: r≈0.9994 OK: N_G=256

1/Proton Lifetime ∝ **[QCD param.]** * [NewPhys. param]

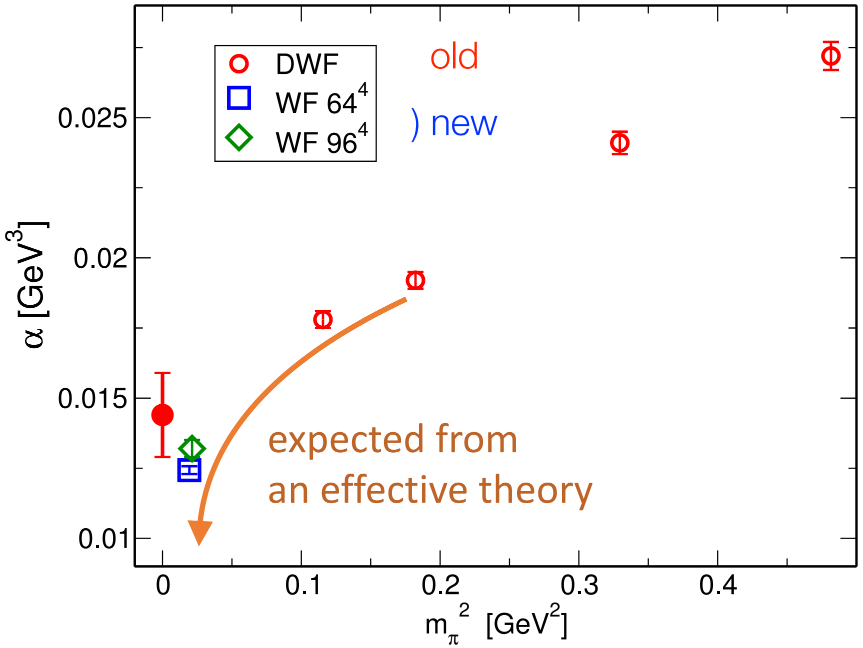


$$\mathrm{err}_{(\mathrm{imp})} \approx \mathrm{err}\sqrt{2(1-r)+\frac{1}{N_G}},$$

- **old: long distance extrapolation**

vs

- **new: on physical point simulation**



Aoki, Kuramashi, Shintani, Tsukamoto @ Lattice 2019

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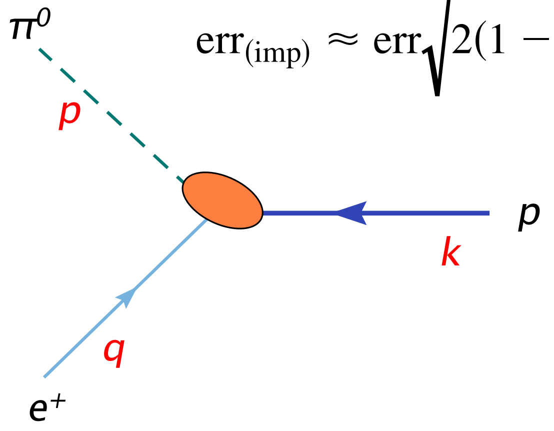

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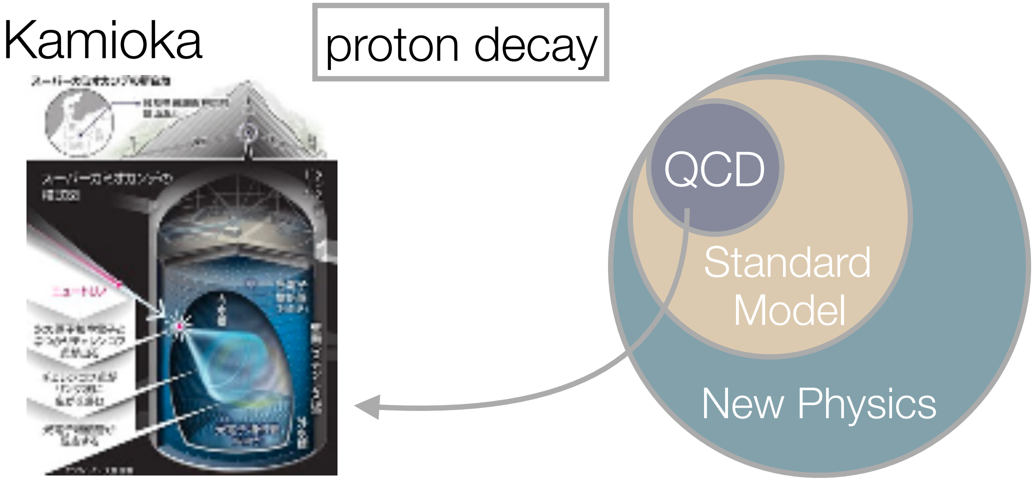

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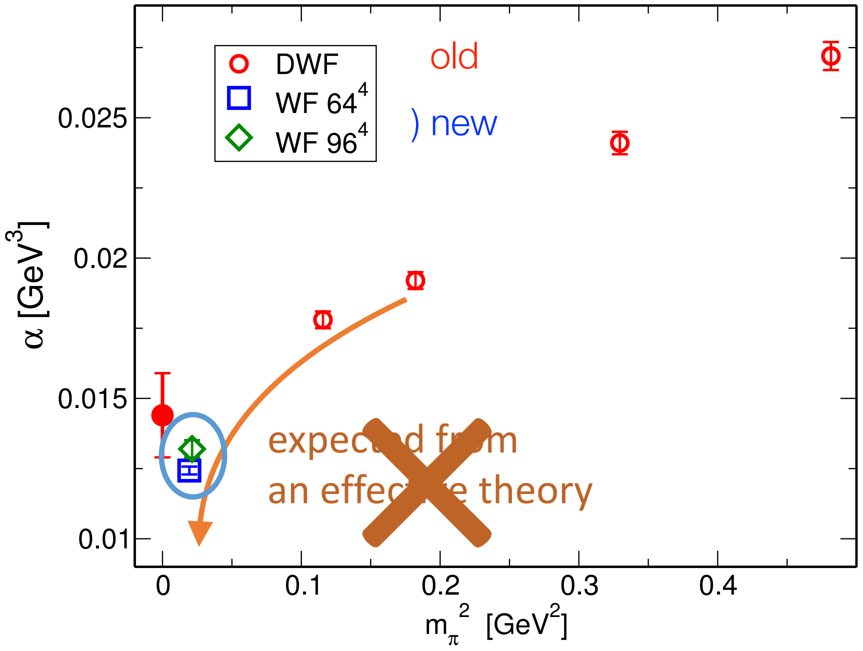

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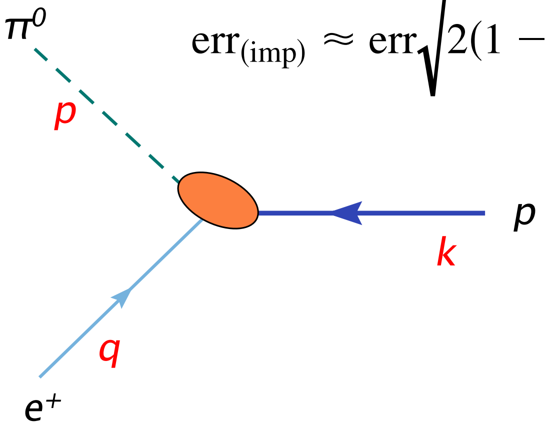


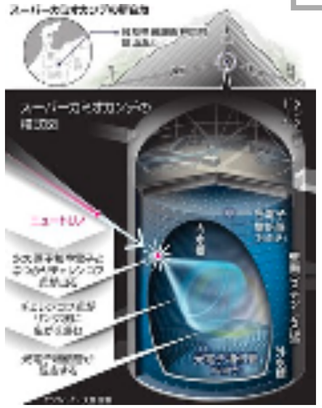
Achievements with K

Hokusai BW and other HPCI resources

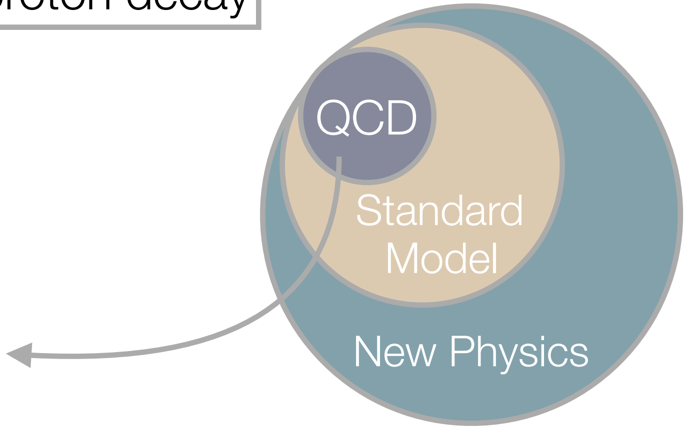
e

- **new: on physical point simulation**

Kamioka



proton decay



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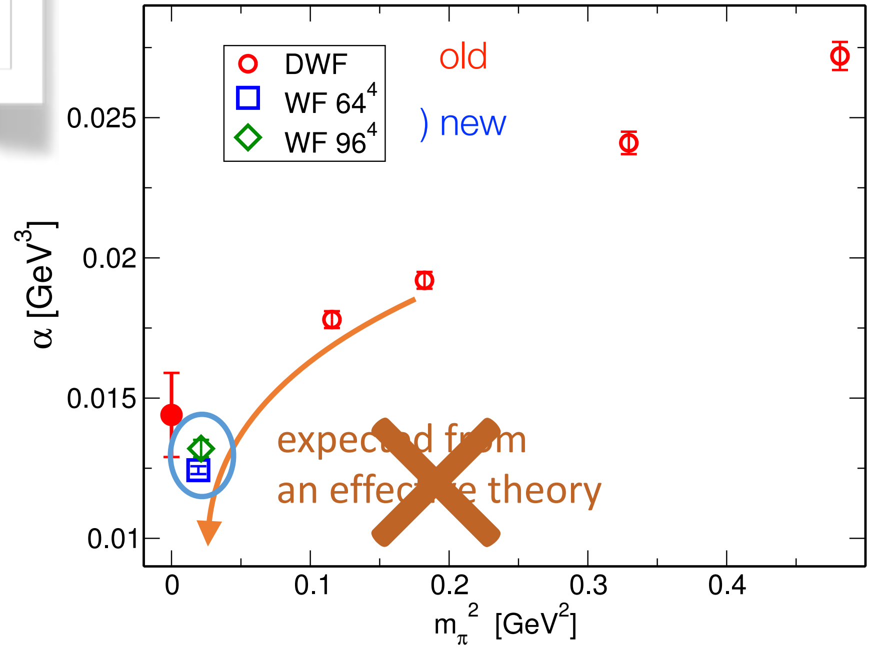
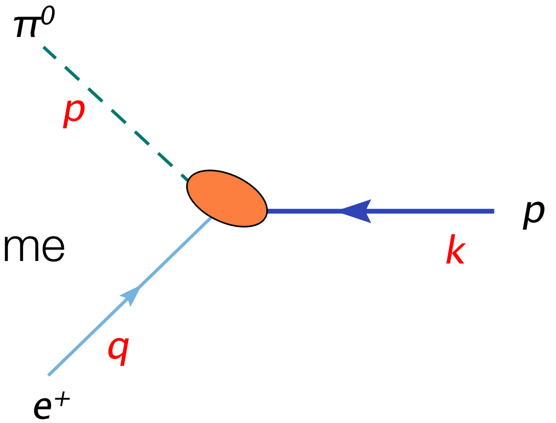


Aoki, Kuramashi, Shintani, Tsukamoto @ Lattice 2019

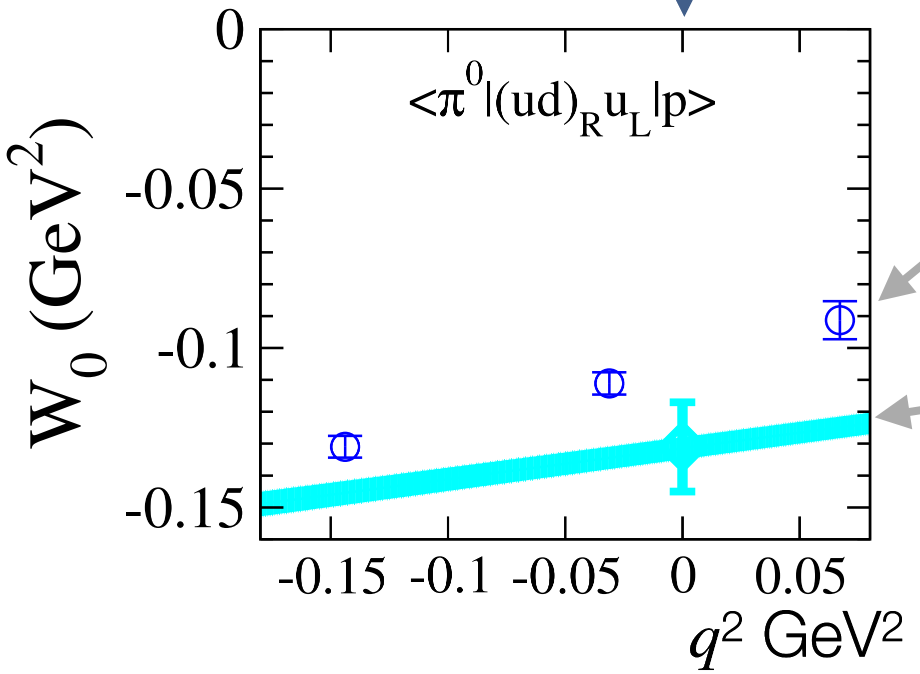
QCD for the tool to bridge new physics

proton decay form factors

- more demanding comp.
- directly related to proton lifetime
- obtaining promising results



on-shell lepton: $-q^2 = m_l^2 = 0$

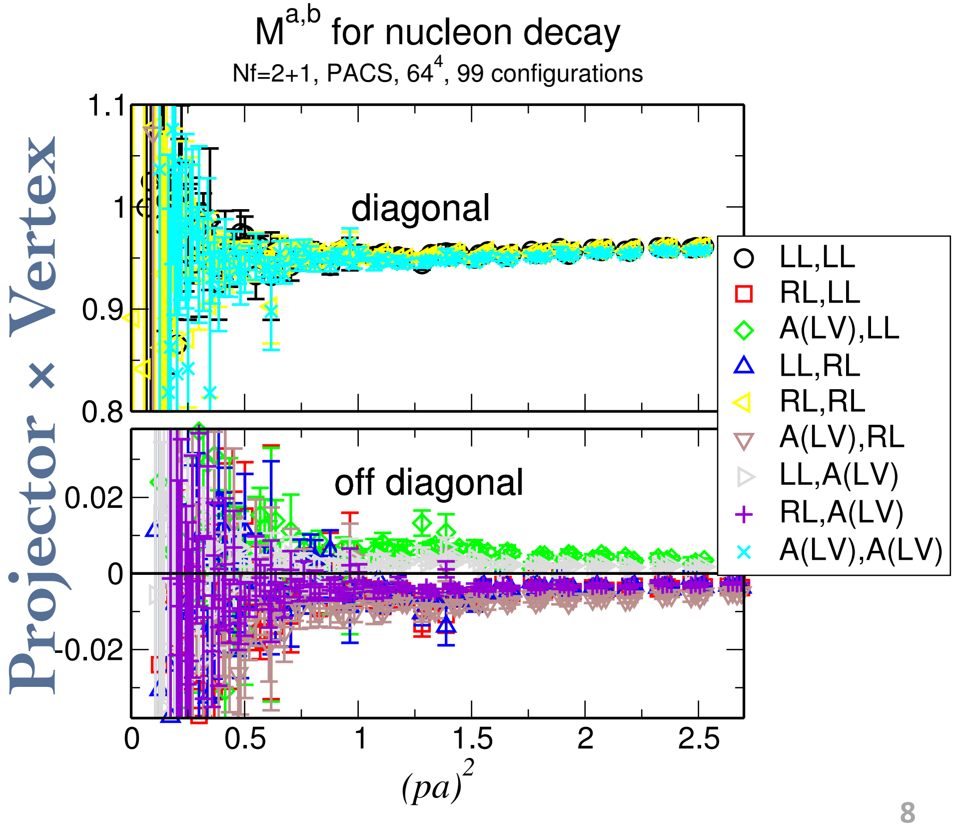


new
(on physical mass)

old
(after long extrpl.)

operator renormalization

- RI/SMOM non-perturbative renormalization
- application: proton decay, nucleon charges
- improved Wilson fermions with 6 stout-link smeared
    - admixture from chiral symmetry breaking is as small as 1%



poster: Aoki, Kuramashi, Tsukamoto, Shintani @ Lattice 2019

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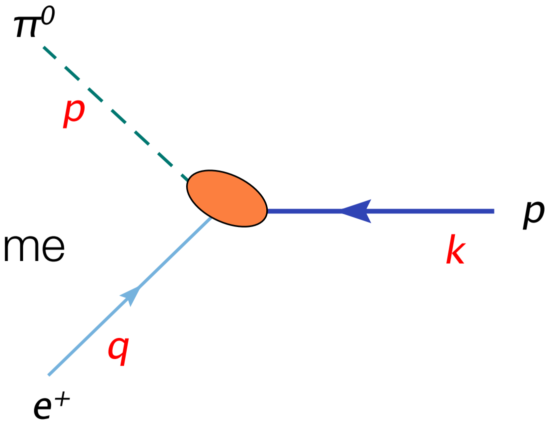

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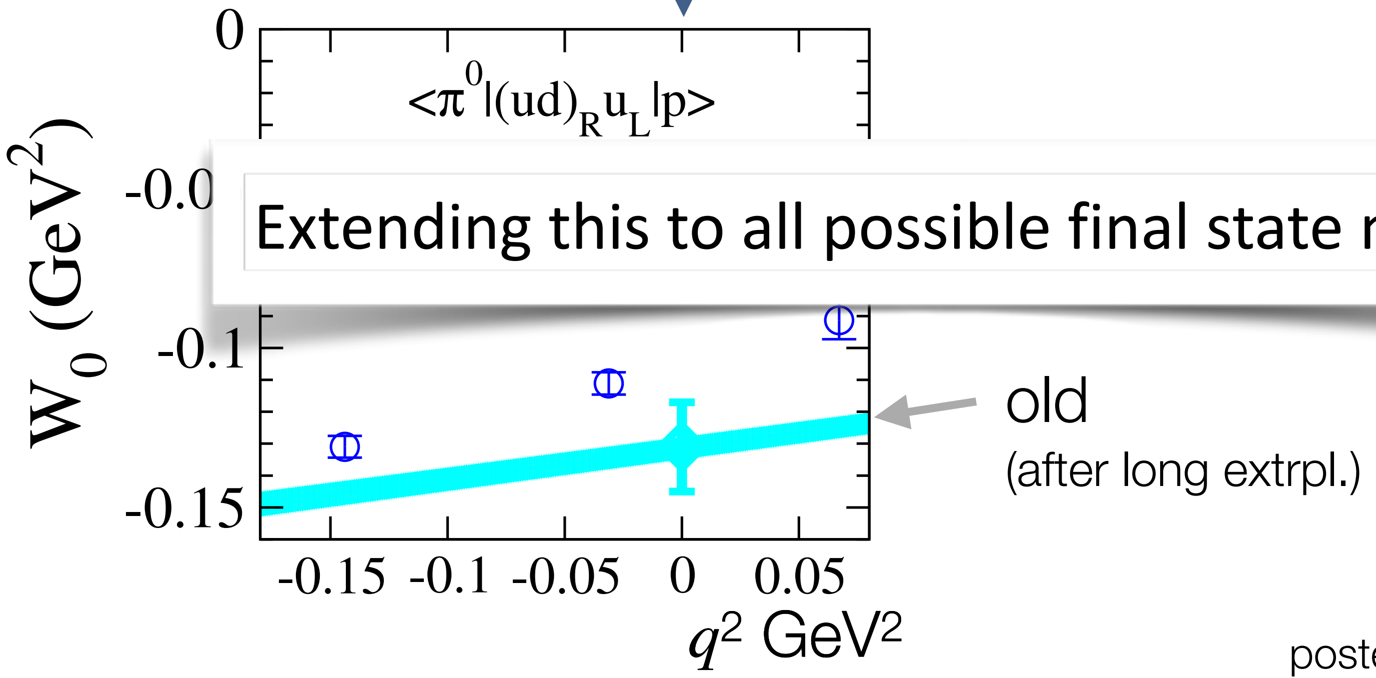

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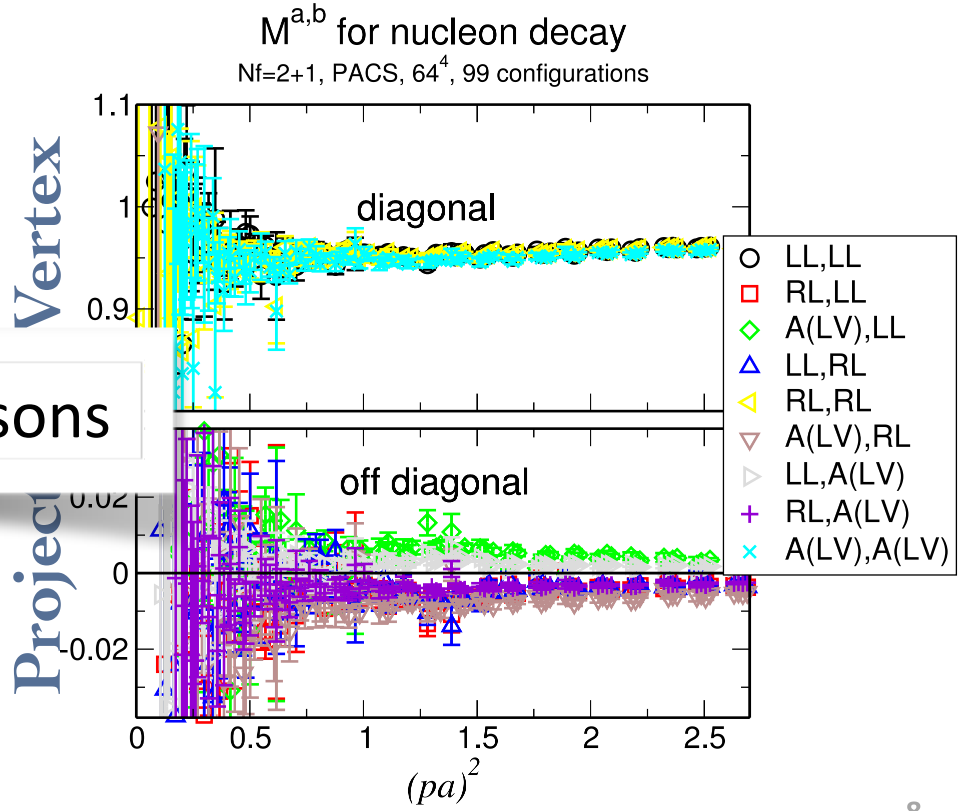
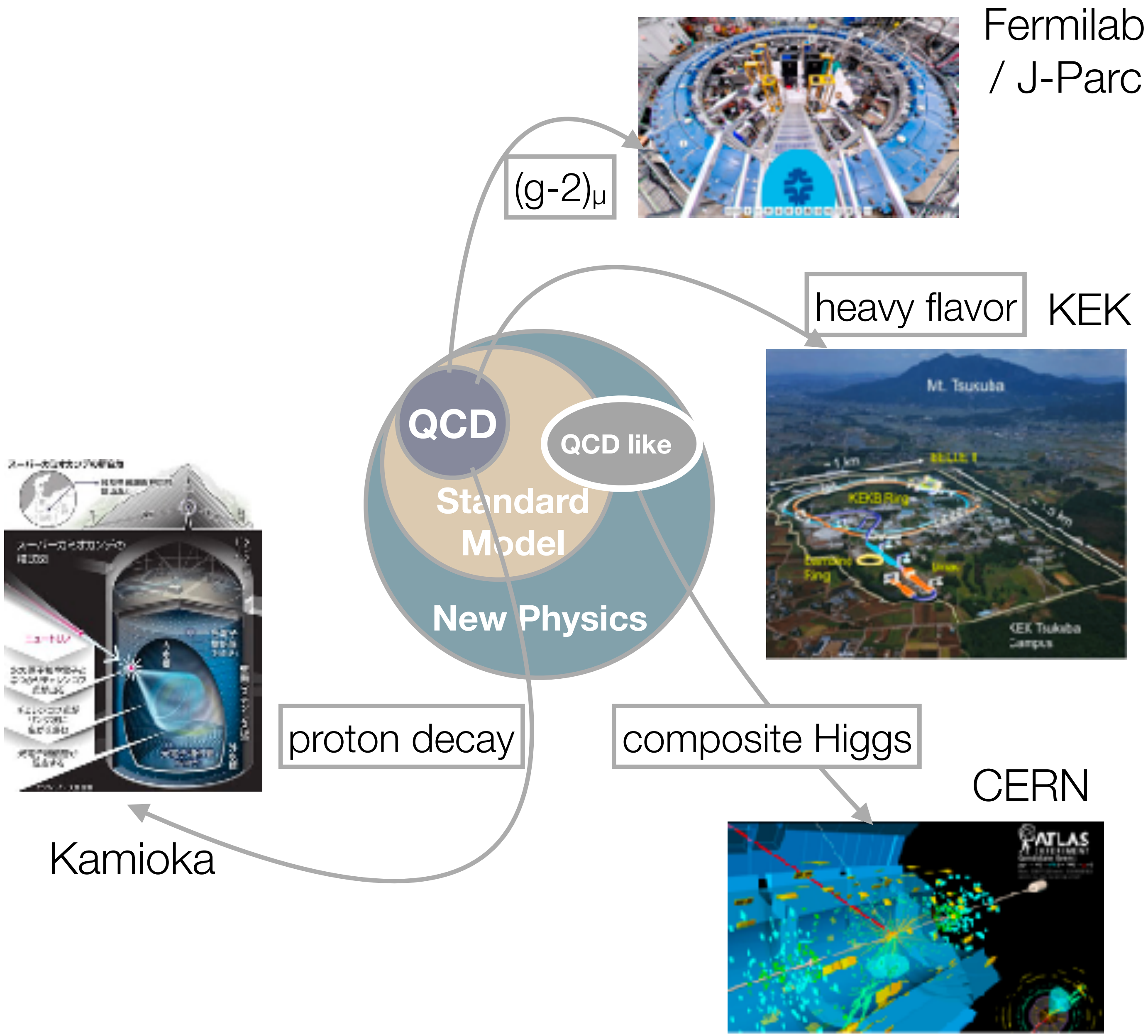


Extending this to all possible final state mesons

poster: Aoki, Kuramashi, Tsukamoto, Shintani @ Lattice 2019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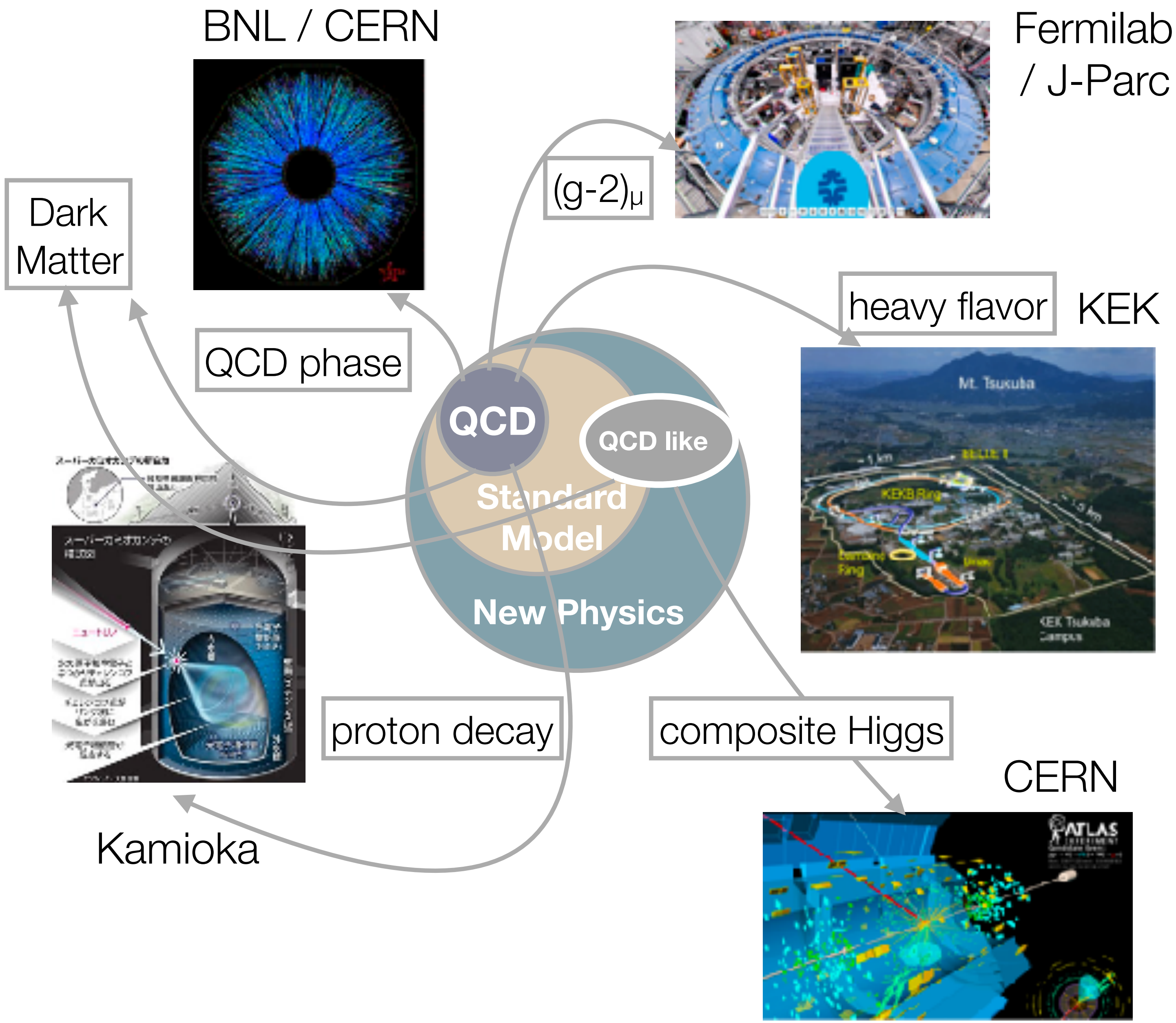
BNL / CERN
Fermilab
/ J-Parc
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Revealing the history of Universe

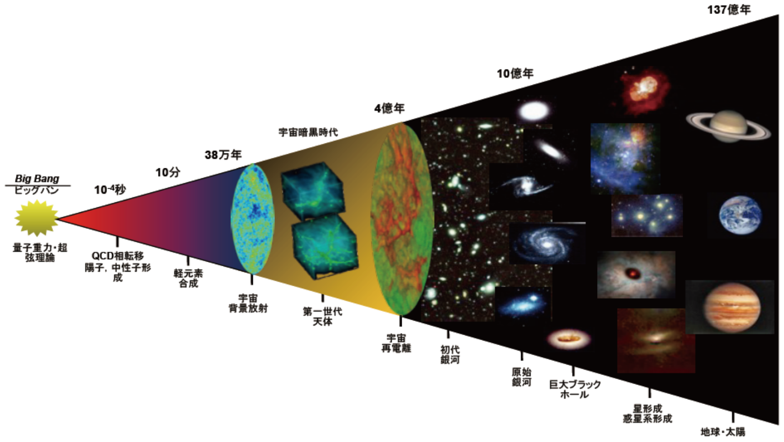
BNL / CERN

Dark Matter

QCD phase

QCD

Standard Model



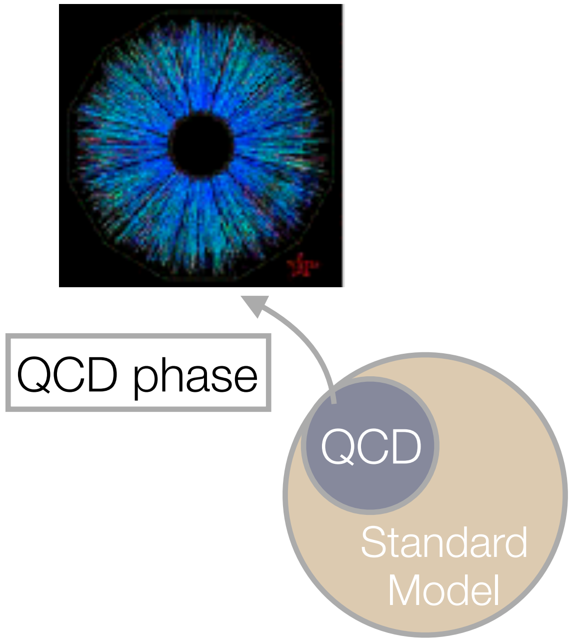
QCD phase : Post-K priority issues #9

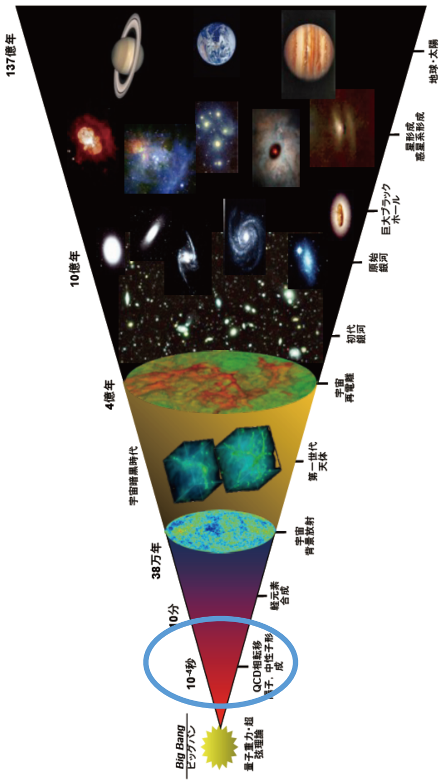
Scientific motivation

- fundamental understanding of QCD phase transition
- Through the use of methods with no compromise
- spontaneous breakdown of **chiral symmetry**
- use of **chiral fermion** algorithm
- in-depth study
    - role of the symmetry
    - role of the anomaly : $U(1)_A$ symmetry
- will give most precise description of the QCD at finite temperature

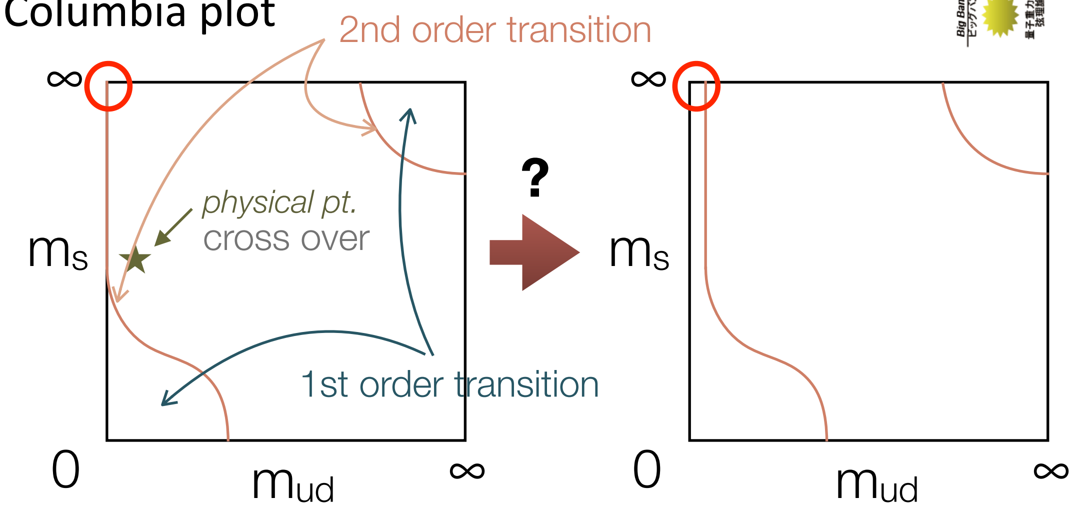
  ➡ experiment / early universe

BNL / CERN





Columbia plot



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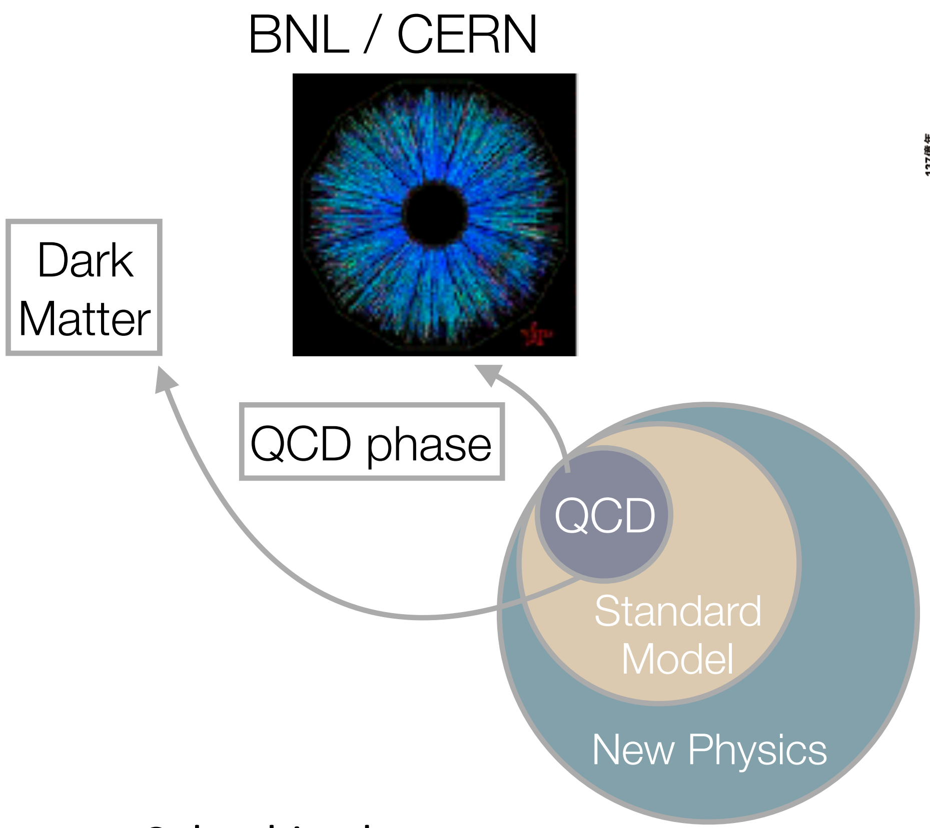

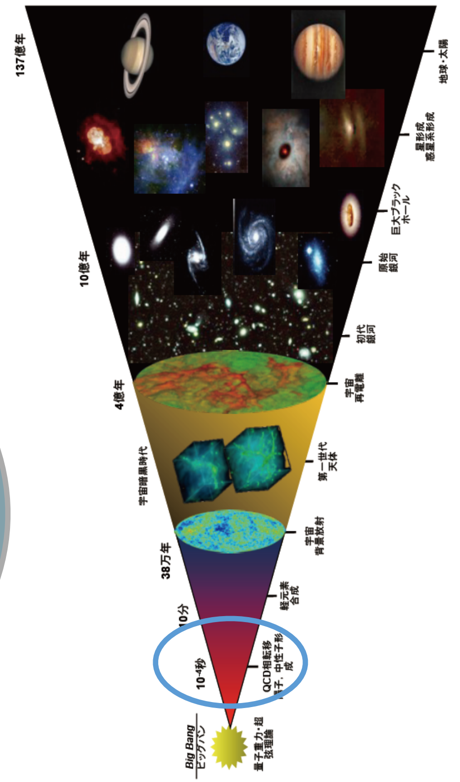

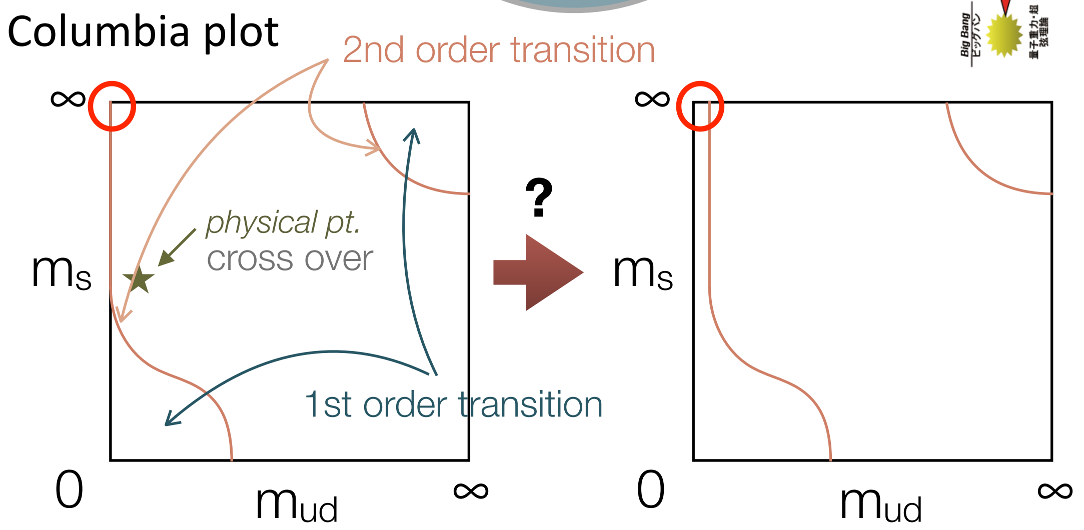

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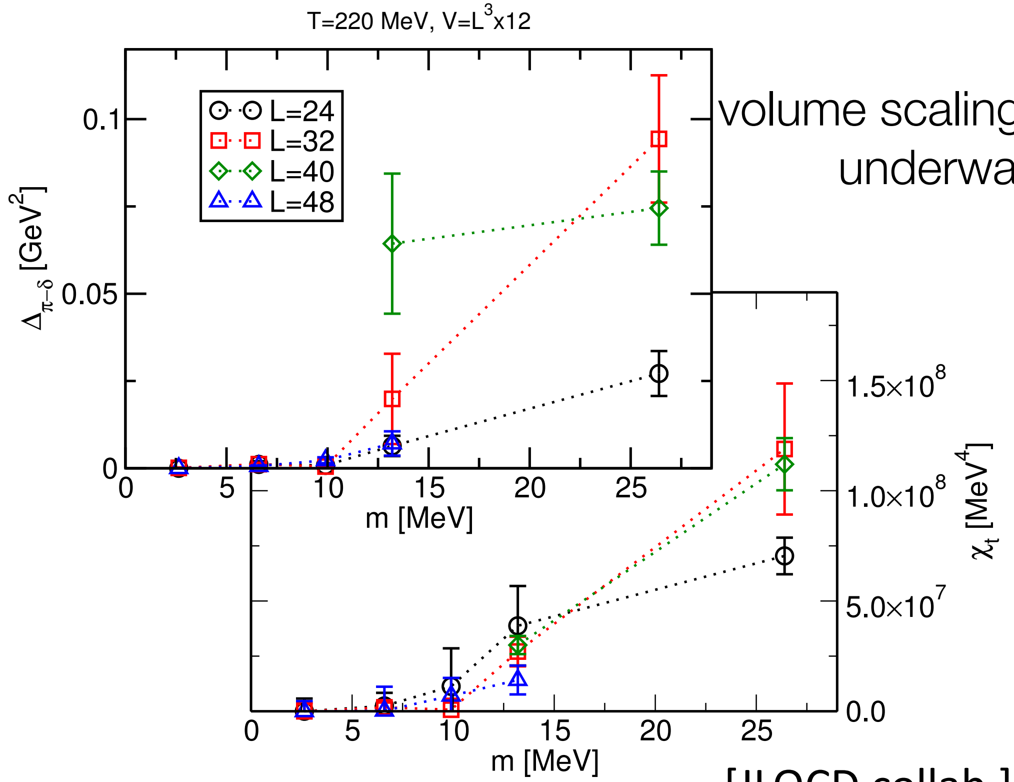
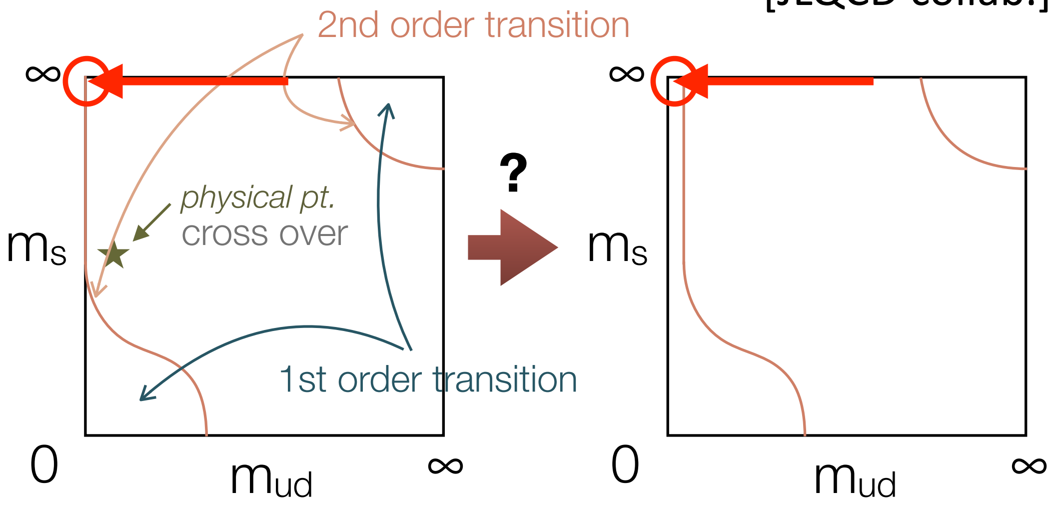
- demanding comp.
- N_f=2 ($m_s \to \infty$) phase: yet to be conclusive
  - knowledges being acquired
- interesting development of fate of $U(1)_A$
- around physical point → Fugaku



volume scaling study underway

[JLQCD collab.]



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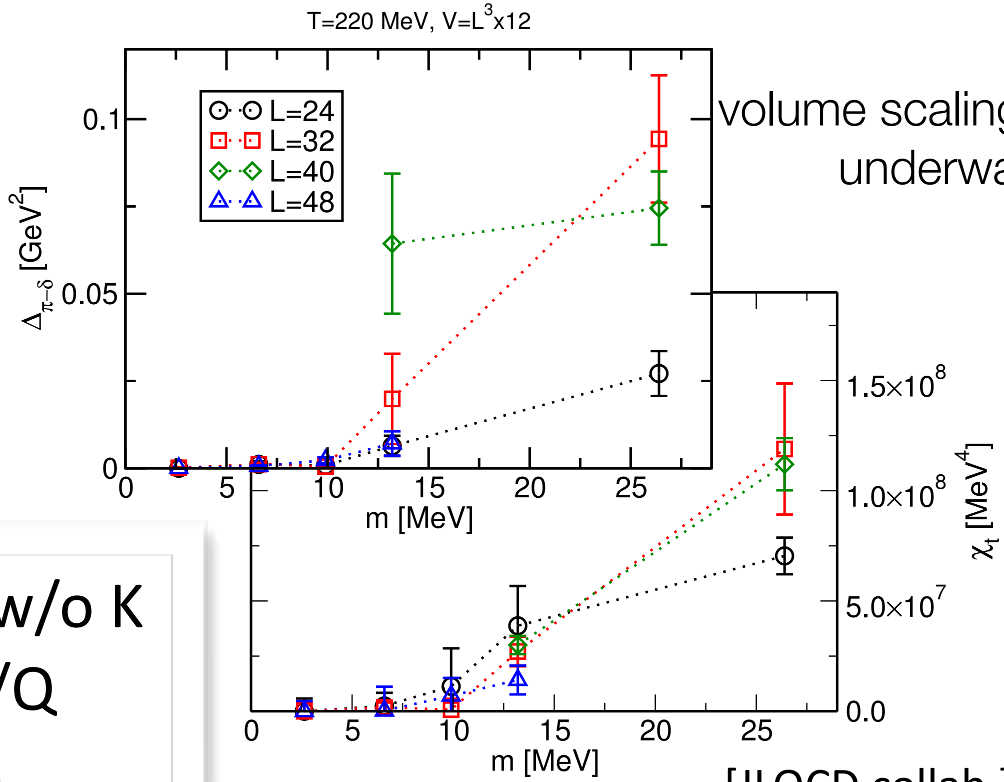
Achievements w/o K
KEK Blue Gene/Q
Oakforest PACS



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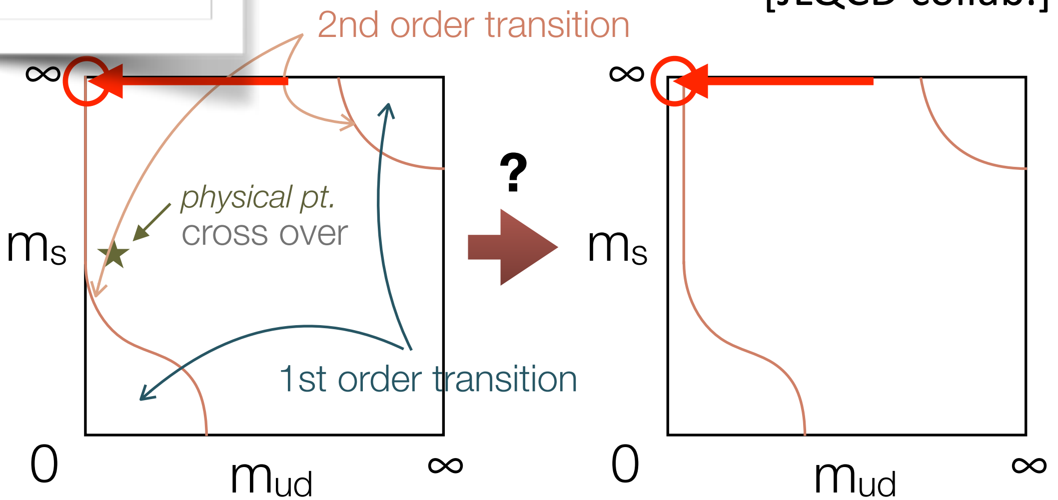
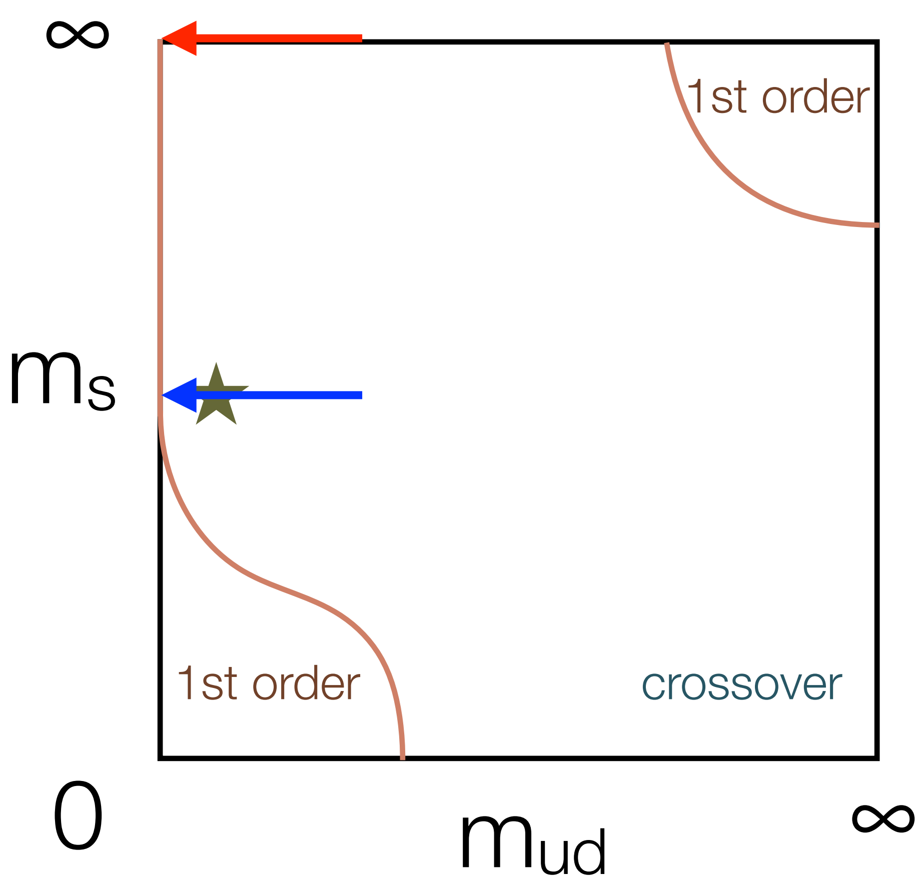


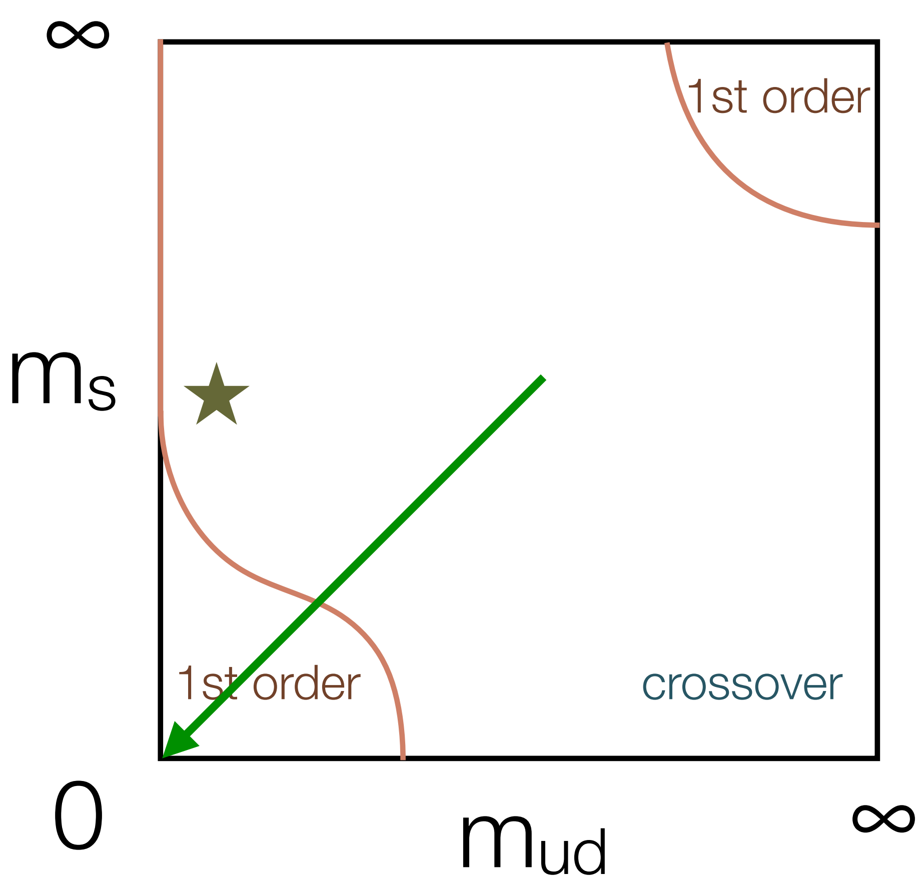
plans for QCD phase

direct access to physical point and surrounding area



Planned to be explored on **Fugaku**

degenerate 3 quark system: simpler



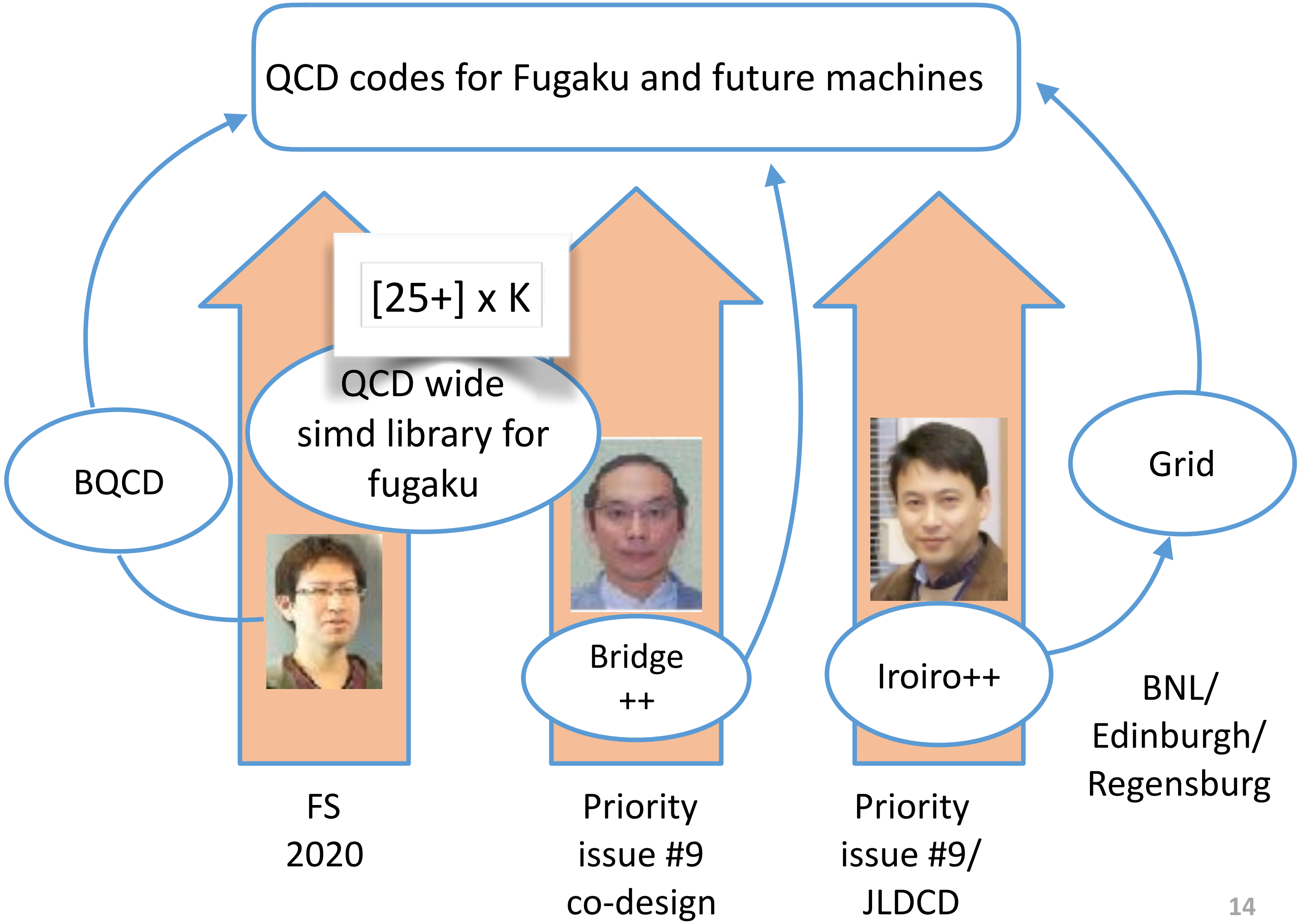
Started using HPCI resources and Hokusai-BW

computational technologies and developments

ongoing projects and plans

1) QCD code packaging and tuning for Fugaku
    - lowest revel taken from co-design activity
    - higher level, packaging, tuning
2) algorithms for chiral fermions for big volume
    - mostly for linear solvers
    - AMA, multigrid, etc
3) new algorithms / developments
    - AI: may be used for optimizing implicit parameters / initial guess
        - integration path (start, end fixed)
        - MD parameters
    - tensor network
4) collaborations for developments and science
    - priority issue #9 and successors
    - international

Post-K/Fugaku development in the team

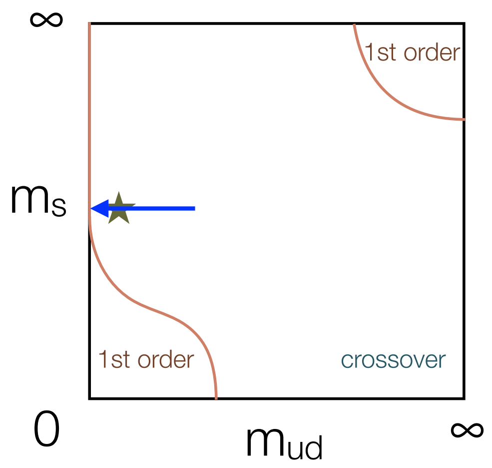


Use of Fugaku w/ our developments

extends the reach of simulation

- with Domain-wall Fermions (chiral)
- QCD phase
  - ✳N_t=16   for N_f=2+1 (dynamical u,d,s quarks)
    - real chiral simulation for phase transition
- Heavy flavor
  - ✳$M_B\, a \lesssim 1$
    - to control discretization error
    - B→πlν, etc

Use of Fugaku w/ our developments



Ultimate understanding of QCD phase

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  - real chiral simulation for phase transition

Previously, N_f=2 (only u,d quarks) or N_t=8

→ lattice spacing $a^{new}/a^{old} = 1/2$

- Heavy flavor

  ✳$M_B\, a \lesssim 1$

  - to control discretization error
  - $B \to \pi l \nu$, etc

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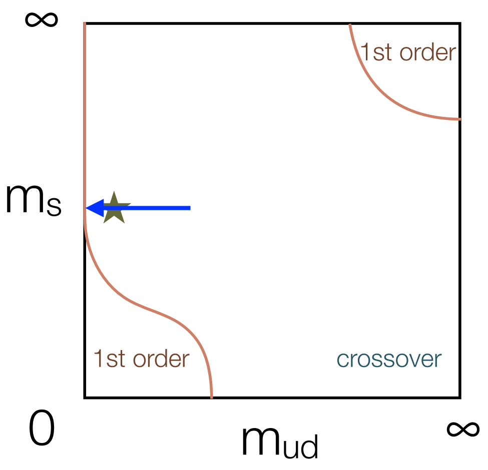

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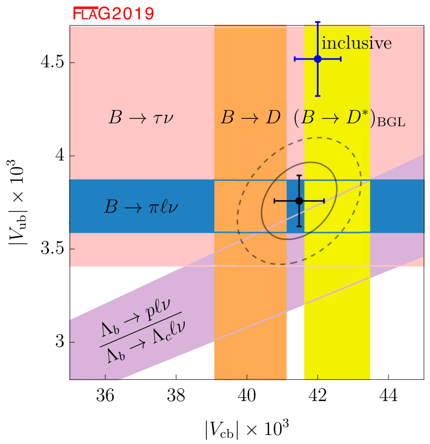

More stringent constraint on Standard Model

Previously, N_f=2 (only u,d quarks) or N_t=8

→ lattice spacing $a^{new}/a^{old} = 1/2$

Previously $M_B\, a \simeq 2$

→ lattice spacing $a^{new}/a^{old} \lesssim 1/2$