RBRC – passion, wisdom and warmth

Yasumichi Aoki

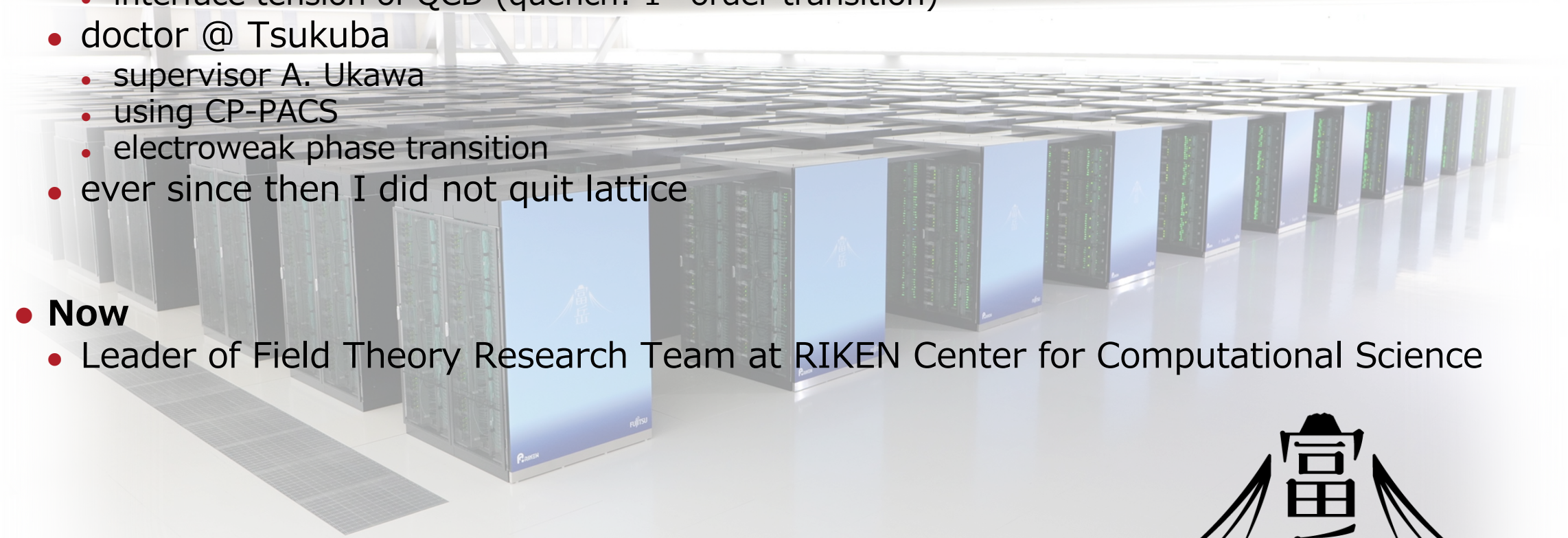
RBRC 25 years anniversary @ BNL

RIKEN R-CCS

who am I ?

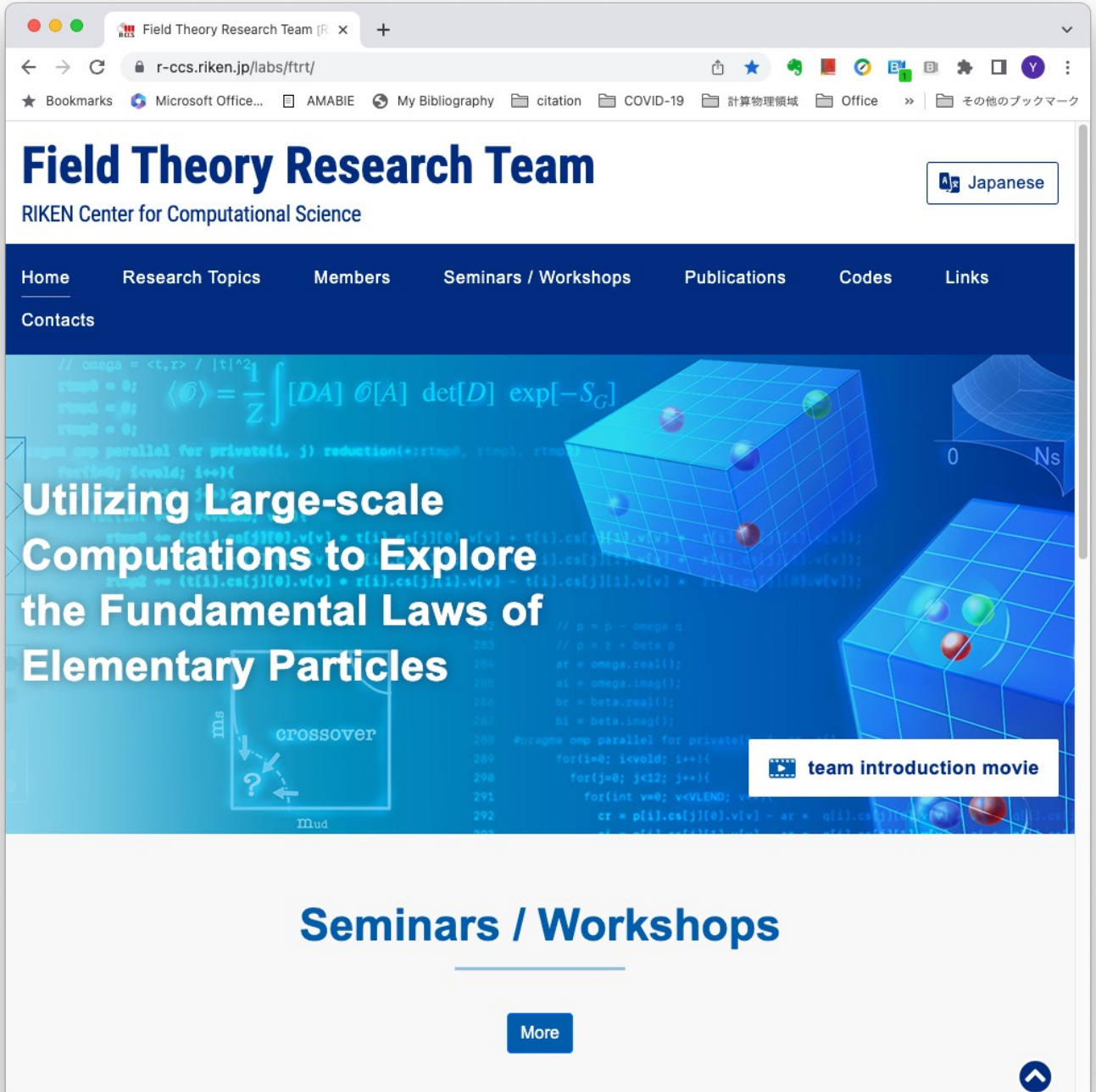
- **Lattice guy**
  - started lattice QCD computation from master coarse @ Tsukuba (1991)
    - supervisor Y. Iwasaki / K. Kanaya
    - using (prototype of) QCDPAX
    - interface tension of QCD (quench: 1st order transition)
  - doctor @ Tsukuba
    - supervisor A. Ukawa
    - using CP-PACS
    - electroweak phase transition
  - ever since then I did not quit lattice

- **Now**
  - Leader of Field Theory Research Team at RIKEN Center for Computational Science



Supercomputer Fugaku

Members

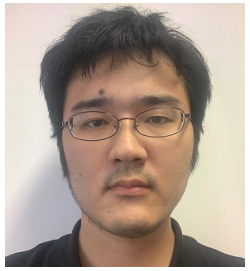


I. Kanamori

Y. Nakamura

K. Nitadori

J. Goswami



K. Nakayama

Z. Yu

R. Tsuji

S. Aoki

S. Hashimoto

D. Lin

episode 1on1

- **1on1 (meeting)**
  - PI meets one member
    - to hear / understand (personal) problems / issues
    - to guide member for directions
    - to try think together to help member to find solutions
  - must not discuss research (tasks)
  - good to starts with a simple question
    - and continue, expand,

  - my team: 1 research scientist, 2 concurrent technical scientists, **3 postdocs, 1 JRA**
  - once/moth for all young researchers for 30 min

  - Q to each member last time:
    - what do you think is most important element(s)/skill(s) one should have for a successful scientist ?

  - A from one young researcher
    - human relation!

    this answer is totally unexpected one to me…, and realized I might have been very lucky…

my relation with RBRC

- Apr. 1997 ～ Mar. 2000　Assistant @ Tsukuba CCS
- May 2000 ～ July 2003　RBRC research associate
- Aug. 2003 ～ Aug. 2006　Wuppertal
- Sep. 2006 ～ Nov. 2010　RBRC fellow
- Dec. 2010 ～ Apr. 2016　Kobayashi-Maskawa Institute, Nagoya
- May. 2016 ～ Jan. 2019　KEK
- Oct. 2016 ～ July 2018　RBRC fellow (cross appointment)
- Oct. 2018 ～　R-CCS (Kobe, Japan)

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All together: 100 months = 8 years and 4 months

(assuming cross appointment : ~ 50% RBRC)

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- **May 2000 ～ July 2003　RBRC research associate**

May 2000:

RBRC RA Kazu Itakura and myself joined
: Daniel Boer, Mat Wingate, Juergen Schaffner Bielich, Yasui, Shoichi Sasaki, Yasushi Nara,

RBRC event – Thursday lunch talk – people can order Japanese bento box
director TD Lee always shows up, questions, encourages all

I got really nervous at the 1st experience, but, getting used to it

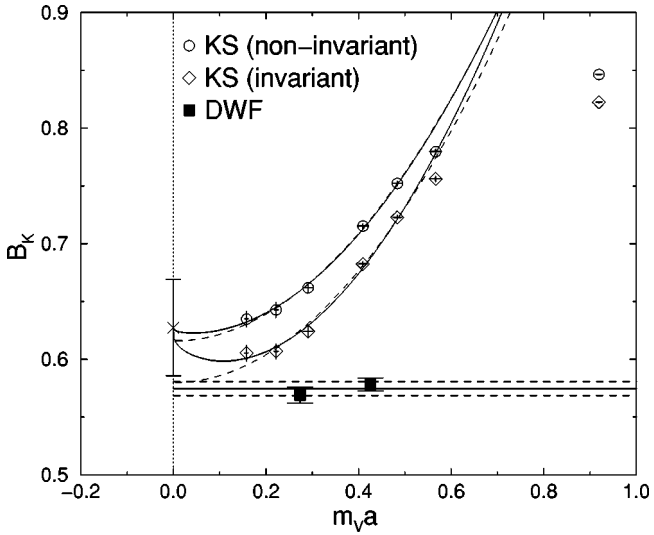
owing TD and everyone's warm personality

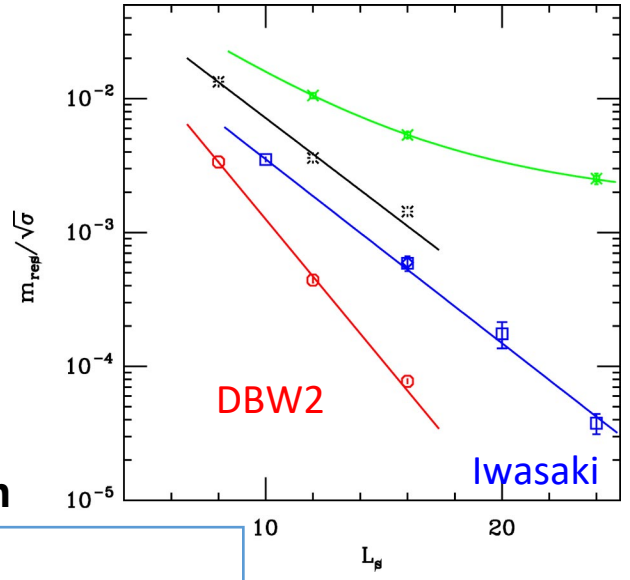
celebration party hosted by TD

- Yasushi Nara's and Aoki's marriages celebrated at the same time in RBRC

my research around year 2000

- **Domain wall fermion (quench)**
  - encouraged by the success of Blum-Soni
  - at *CP-PACS* collaboration ~1998~
    - S. Aoki, **T. Izubuchi**, Y. Taniguchi, Y. Aoki,
    - Goodness of chiral symmetry depend on gauge action
      - Iwasaki action better than Wilson
    - Kaon bag parameter B_K
    - + J. Noaki : ε'/ε
  - RBC (RIKEN-BNL-Columbia)
    - with **K. Orginos** (joined in autumn 2000~)
    - Gauge action dependence more in depth
      - DBW2 action better than Iwasaki
    - *QCDSP* : cps++, debugging qcdsp (finding faulty node is not easy..)
    - senior members: **T. Blum**, N.Christ, R.Mawhinny, S.Ohta, A. Soni
  - RBC
    - proton decay ME project started w/ discussion with Soni
      - this later become my baby project which is being continued by now
        - got very useful knowledge and skills throughout 1st round of this project
        - I brought up the project and I was brought up by this project
      - essential – new NPR scheme built mostly by discussion with **Chris Dawson**





Human relation !
I met right persons in right timings. They are all passionate and cool on what they are facing.

proton decay matrix elements

- **Non perturbative renormalization (NPR) of 3 quark operators**

$$\mathcal{O}^{\Gamma\Gamma'}_{uds} = \epsilon^{ijk}(u^{iT}C\Gamma d^j)\Gamma' s^k$$

- **classification resembles weak 4 fermi operators for Kaon decay**

TABLE II. Classification of the nucleon-decay three-quark operator $\mathcal{O}^{\Gamma\Gamma'}_{uds}$ by parity ($\mathcal{P}$) and switching ($\mathcal{S}$) ($u \leftrightarrow d$).

	$\mathcal{S}^-$			$\mathcal{S}^+$	
$\mathcal{P}^-$	SS	PP	AA	VV	TT
$\mathcal{P}^+$	SP	PS	$-AV$	$-VA$	$T\tilde{T}$

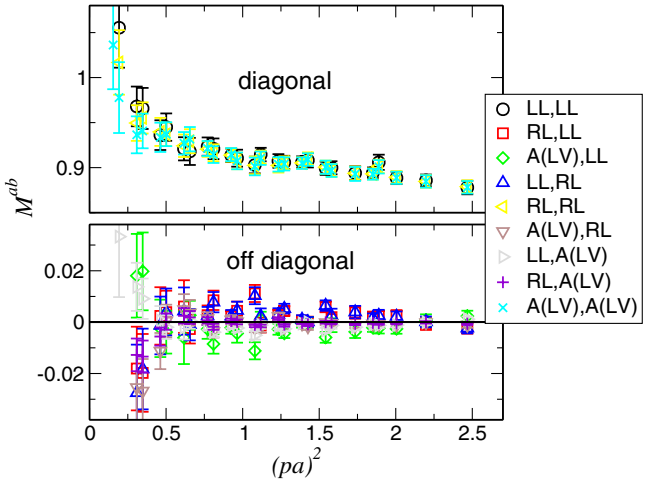


FIG. 2 (color online). Mixing matrix $M^{a,b}$ in the chirality basis at the chiral limit $m_f \to -m_{\rm res}$.

- **RI/MOM scheme : chiral-violating operator mixing suppressed**
- **RI → MSbar matching → usable in phenomenology**

Skills: NPR, PR

Travel to USA from Germany (2004)

my relation with RBRC

- Aug. 2003 ~ Aug. 2006 Wuppertal
- **Sep. 2006 ~ Nov. 2010 RBRC fellow**

September 2006 back to Long Island from Germany

Thursday lunch talk continues w/ presence of N. Samios / L. McLerran (YA management)

LQCD: RBC → RBC/UKQCD collaboration for 2+1 flavor DWF studies

joint call (phone) once a week for each project

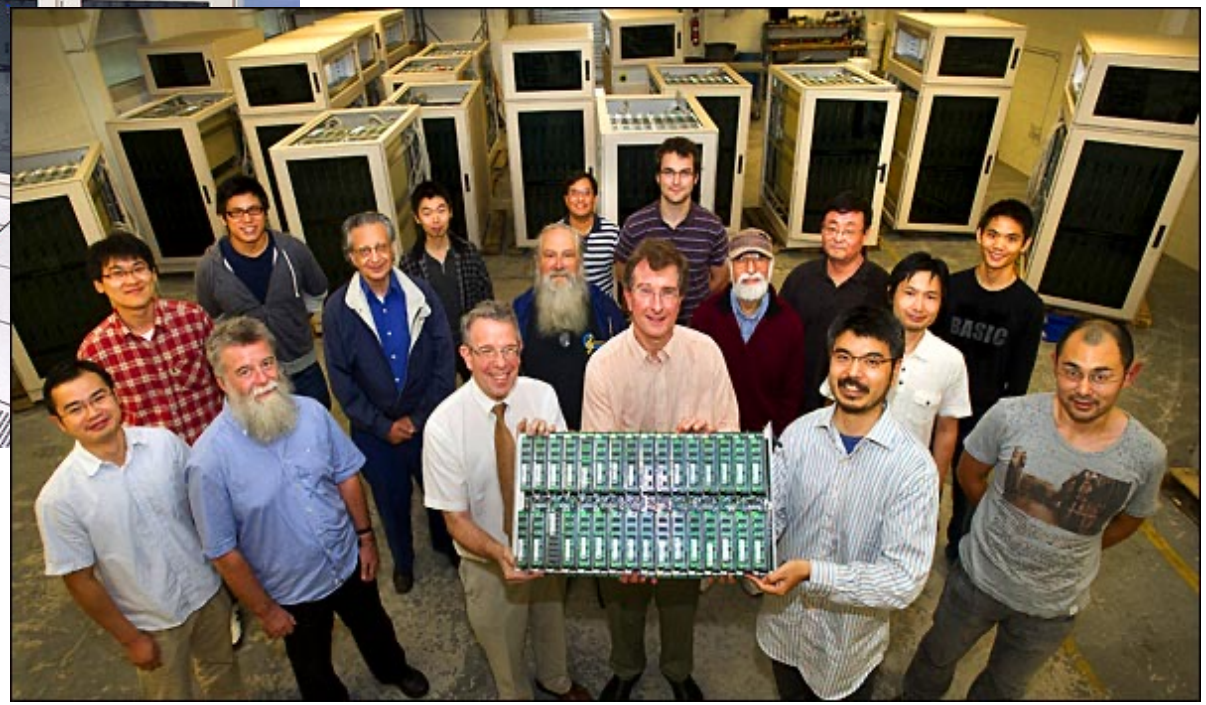
I joined calls (discussion over phone was actually challenging to me)

- general 2+1 flavor DWF applications (mass, bag parameter etc)
  - UK: C.Sachrajda, P.Boyle, ,
- non-perturbative renormalization
  - Later I was coordinating the call and discussion
  - SMOM scheme ← realization as a scheme of Norman's idea of non-exceptional momentum
    - C. Sturm (PQCD guy!)
  - SMOM BK scheme: P. Boyle, et al

I was also involved in the projects

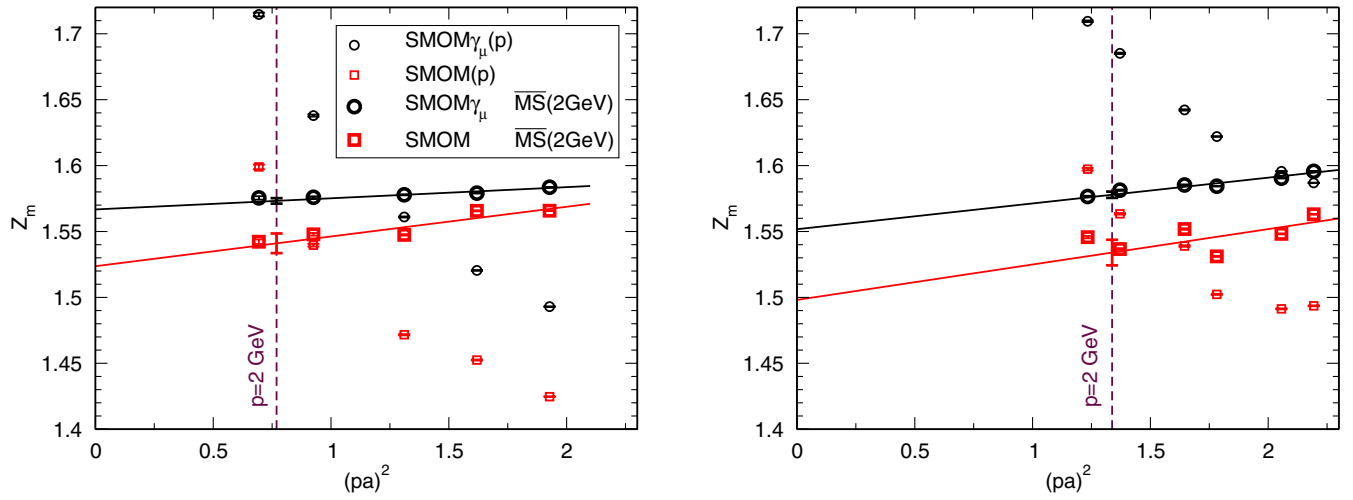
- neutral B meson mixing : RBC: **T. Ishikawa**, R. van de Water, O. Witzel, **C. Lehner**
- proton decay LEC with UK: P. Cooney, L. Del Debbio, R. Kenway, C. Maynard, R. Tweedie
- nucleon form factor with **T. Yamazaki,** structure functions **S. Sasaki**

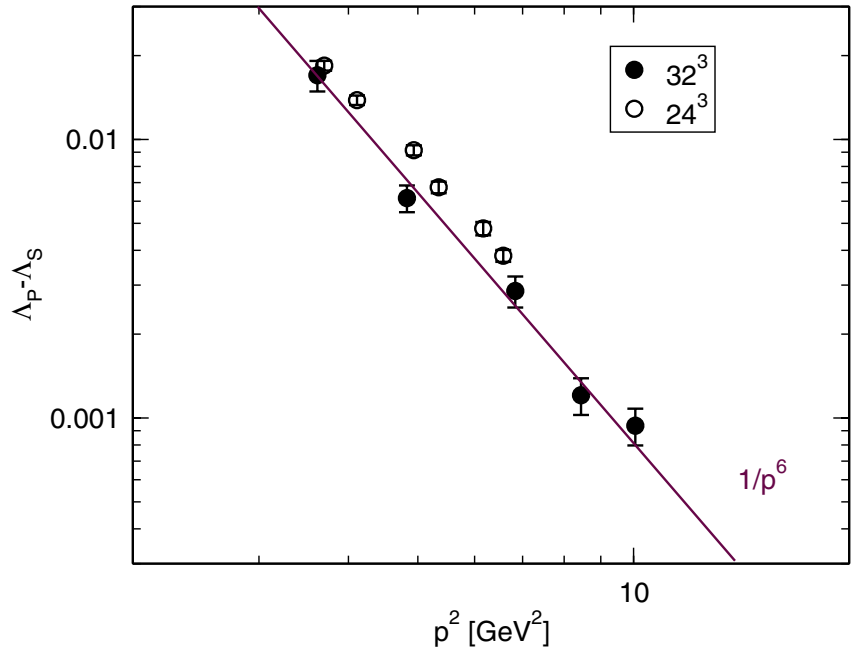
QCDOC

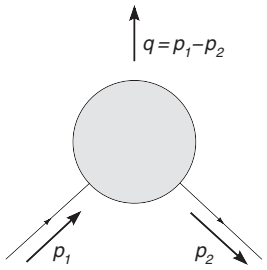


my research around year 2006

- **Domain wall fermion 2+1 flavor in RBC/UKQCD**
  - conventional MOM scheme: exceptional momentum
  - → non-exceptional → NP contamination reduced →







(i) symmetric or nonexceptional momentum configuration:

$$p_1^2 = p_2^2 = q^2 = -\mu^2, \qquad \mu^2 > 0,$$
$$q = p_1 - p_2;$$

(ii) asymmetric or exceptional momentum configuration:

$$p_1^2 = p_2^2 = -\mu^2, \qquad \mu^2 > 0,$$
$$p_1 = p_2, \qquad q = 0,$$

$$m_s^{\overline{\rm MS}}(2\ {\rm GeV}) = 107.3(4.4)_{\rm stat}(9.7)_{\rm ren}(4.9)_{\rm syst}\ {\rm MeV}, \qquad (2008)$$

$$\longrightarrow\ 96.2(1.6)_{\rm stat}(0.2)_{\rm sys}(2.1)_{\rm ren}\ {\rm MeV}, \qquad (2010)$$

recreations

- **ten samurai – softball team**
  - ~2000: captain **Y. Nara, G. Bunce, T. Blum**, and many other Japanese
  - ~2006: captain YA, **I. Nakagawa, C. Marquette**, ..

- **fishing ~ 2006-**
  - **L. McLerran** got me into the sea kayak fishing
    - **K. Fukushima** was more successful
  - I went to shore w/ Kenji many times, occasionally w/ **T. Doi, K. Toru**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my relation with RBRC

- Dec. 2010 ～ Apr. 2016 Kobayashi-Maskawa Institute, Nagoya
  - LatKMI collaboration: many flavor (near conformal) QCD <-> Higgs
    - involving RBRC alumni: H. Ohki, T. Yamazaki, E. Rinaldi (student JPS visitor in 2011)

While back in Japan for 2010~
I was visiting RBRC/BNL occasionally for

- proton decay form factor with: **E. Shintani**
- neutral B meson mixing : RBC: **T. Ishikawa**, **C. Lehner**
- Taku's idea of AMA being ported to proton decay: **E. Shintani**

my relation with RBRC

- May. 2016 ~ Jan. 2019 KEK
  - my main projects are finite temperature DWF in JLQCD (to be continued at Fugaku
- **Oct. 2016 ~ July 2018 RBRC fellow (cross appointment)**
- Oct. 2018 ~ R-CCS (Kobe, Japan)

~one month stay in RBRC some times in year:

- proton decay study @ **physical point : S. Syritsyn,** J-S. Yoo
- discuss MDWF simulation / finite temperature being done in JLQCD
- discuss LatKMI research w/ E. Rinaldi, H. Ohki
- catching up state of the art research: g-2 etc

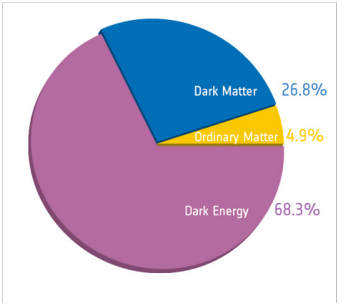
my relation with RBRC

- **May thanks to admin staff for help**
  - ~2000: H. Horie, R. Greenberg, T. Heinz, P. Esposito, T. Ito
  - ~2002: C. Shimoyamada
  - ~2006: Maruyama, E. Adachi
  - ~2016: H. Ito

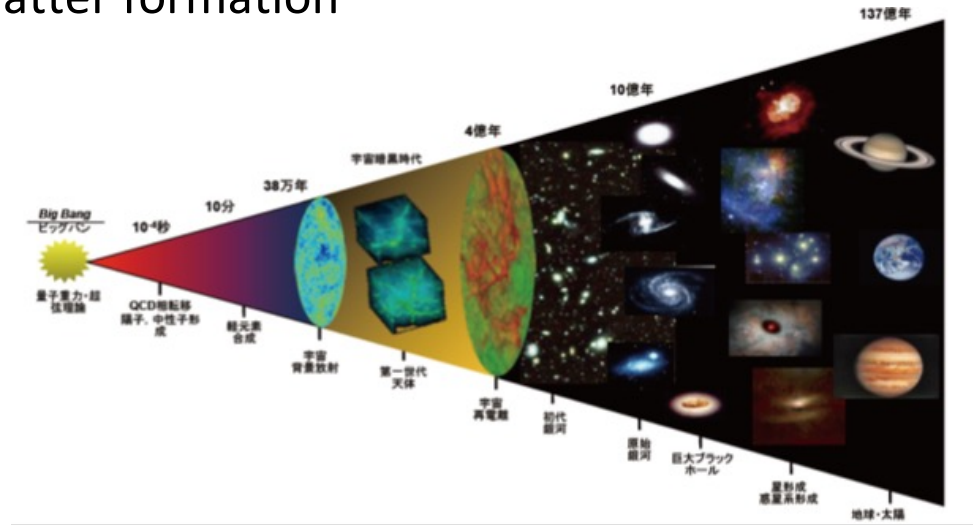
What I'm up to now:

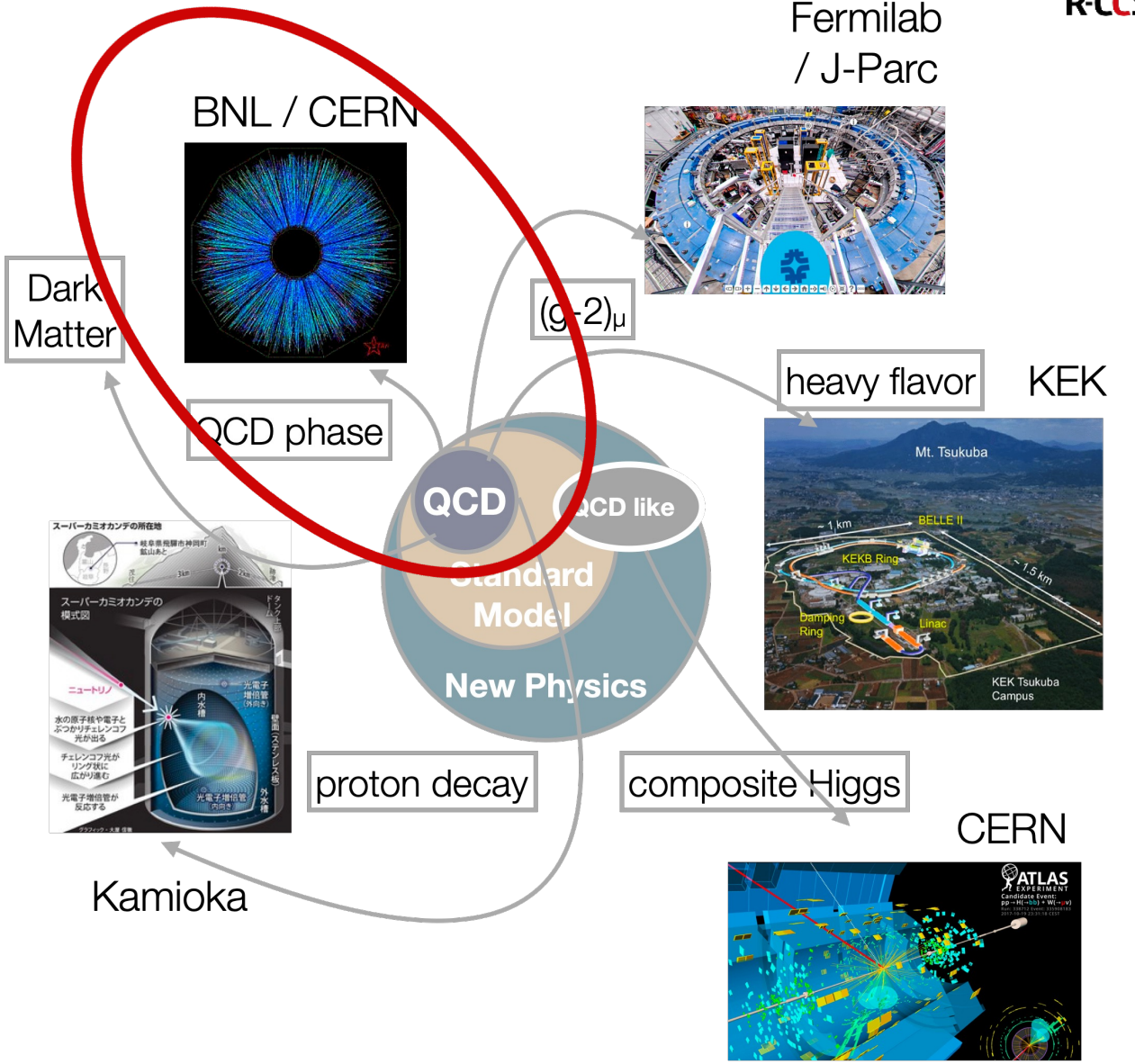
challenges in elementary particle physics
- New Physics search: direct / indirect
- origin of dark matter

…



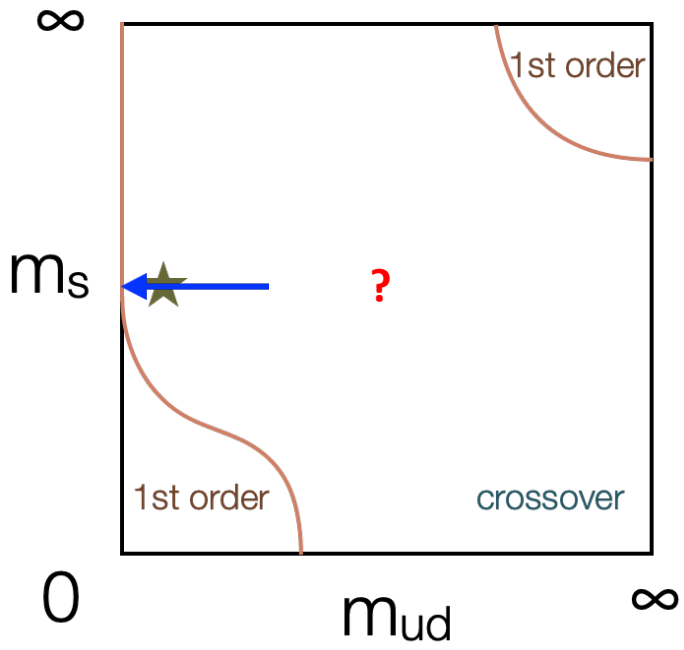
history of universe : phase transition ?
matter formation
…

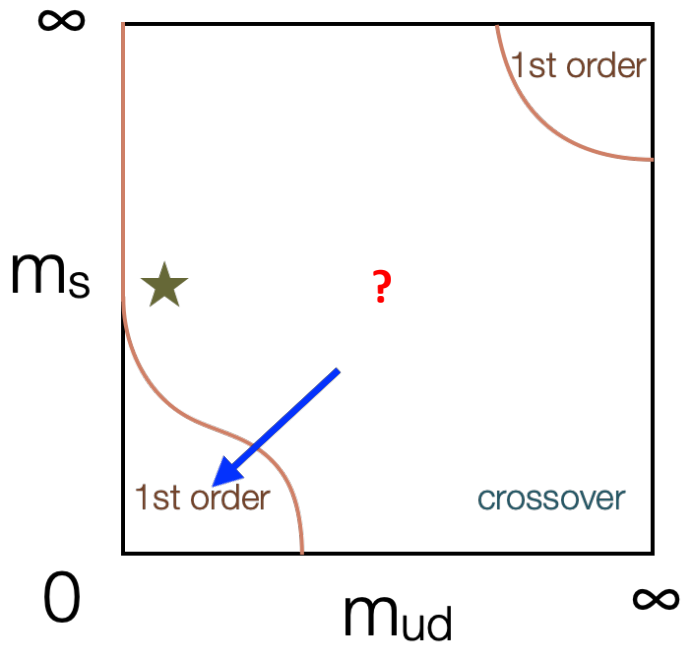




Columbia plot and QCD phase

- **N_f=2+1 thermodynamic property**
  - through chiral symmetric formulation
  - Order of the transition
  - (pseudo) critical temperature
  - Location of the phase boundary
  - Near the physical point
- **Chiral symmetric formulation**
  - Ideal to treat flavor SU(2) and $U(1)_A$ properly
  - Domain wall fermion (DWF) : practical choice
- **DWF and chirality**
  - Fine lattice needed
  - Aiming for a < 0.08 fm (eventually)
  - Current search domain: $0.07 \leq a \leq 0.14$ fm
  - Current criticality range: $0.08 \leq a \leq 0.13$ fm





N_f=2+1 Möbius DWF LCP for ~~FY2021~~ **FY2023-**

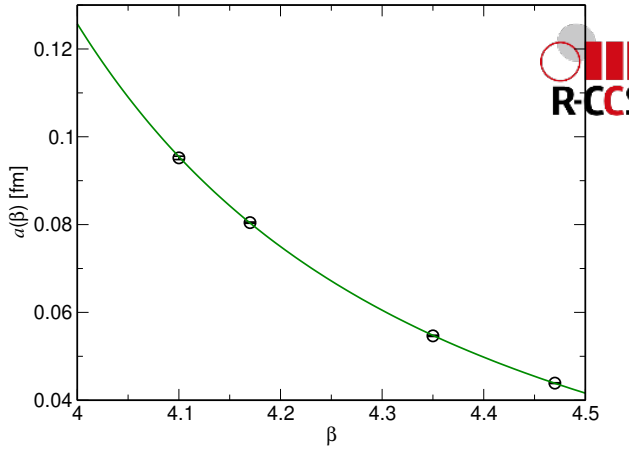
For the Line of Constant Physics: $am_s(\beta)$ with $a(\beta)$

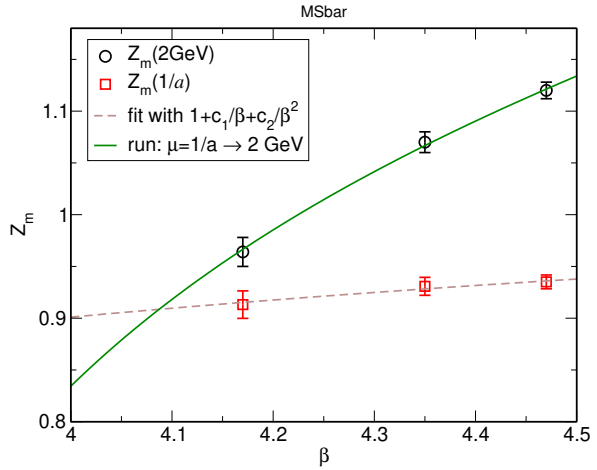
- **Step 1: determine $a(\beta)$ [fm] with t_0 (BMW) input**
  - at $\beta = \mathbf{4.0}, \sout{4.1}^*, 4.17, 4.35, 4.47$

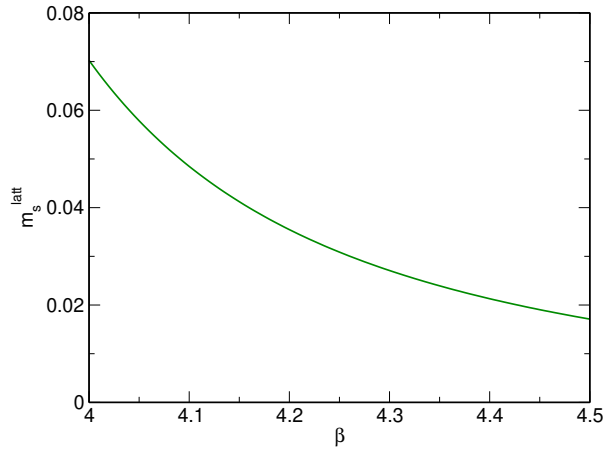
    * β=4.0 new data (previous step5), to add support at small β
- **Step 2: determine $Z_m(\beta)$ using NPR results**
  - at $\beta =$ $4.17, 4.35, 4.47$
  - And use $Z_m(\beta)$ so obtained for $\beta \geq 4.0$: $\beta < 4.17$ region is extrapolation
  - $1/Z_m(\beta)$ will be used to renormalize scalar operator
- **Step 3: solve $am_s(\beta)$ with input (*quark mass input*):**
  - $m_s^R = Z_m \cdot am_s^{latt} \cdot a^{-1} = 92$ MeV
  - $\frac{m_s}{m_{ud}} = 27.4$ (See for example FLAG 2019)
- **See for details in Lattice 2021 proc by S.Aoki et al.**

Do simulation

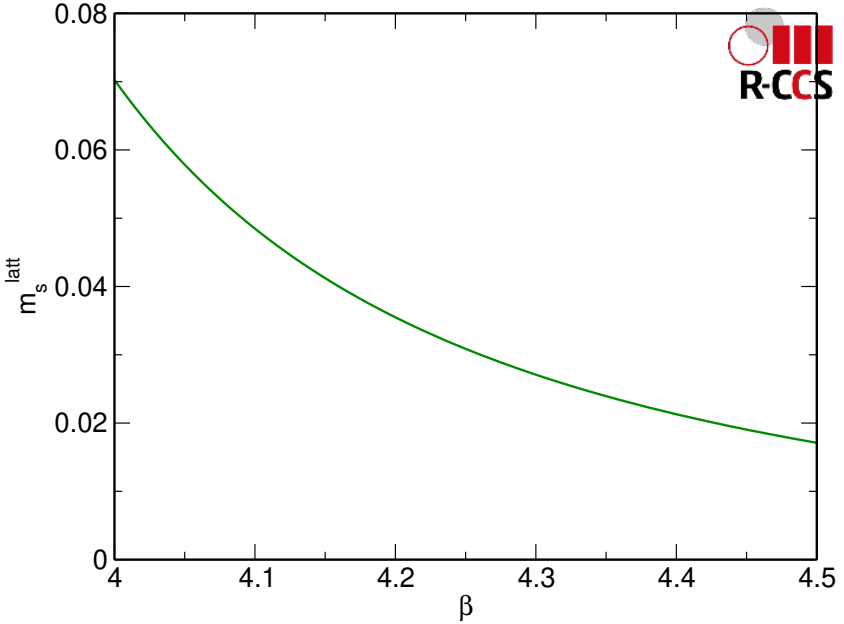
- **Step 4: proper tuning of input mass: correct m_{res}**
- ~~**Step 5: use $a(\beta)$ including new data at $\beta = 4.0$**~~
  - ~~For dimension-full quantities~~







LCP remarks for **FT2023-**

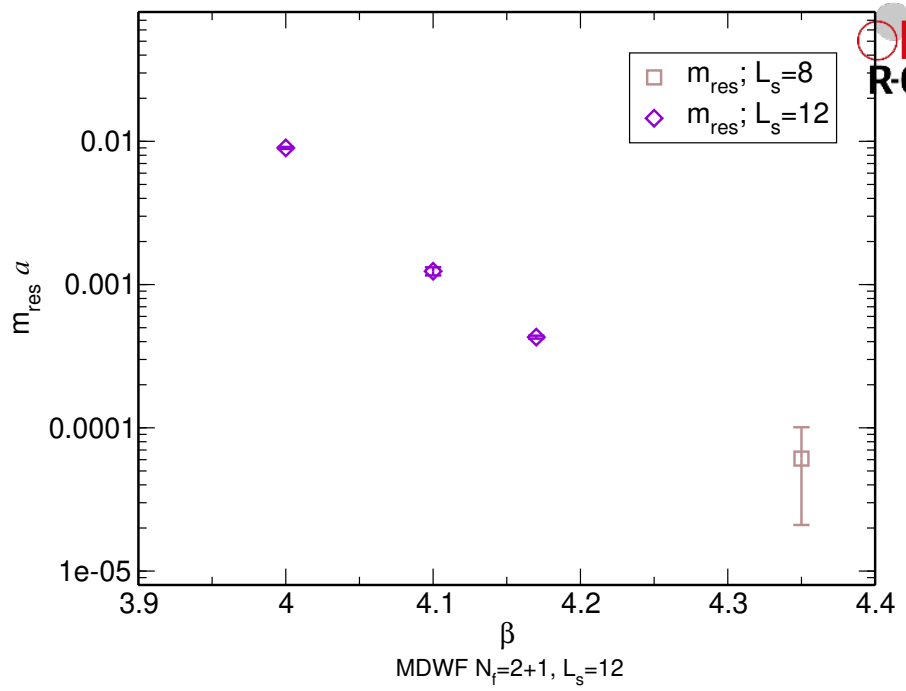


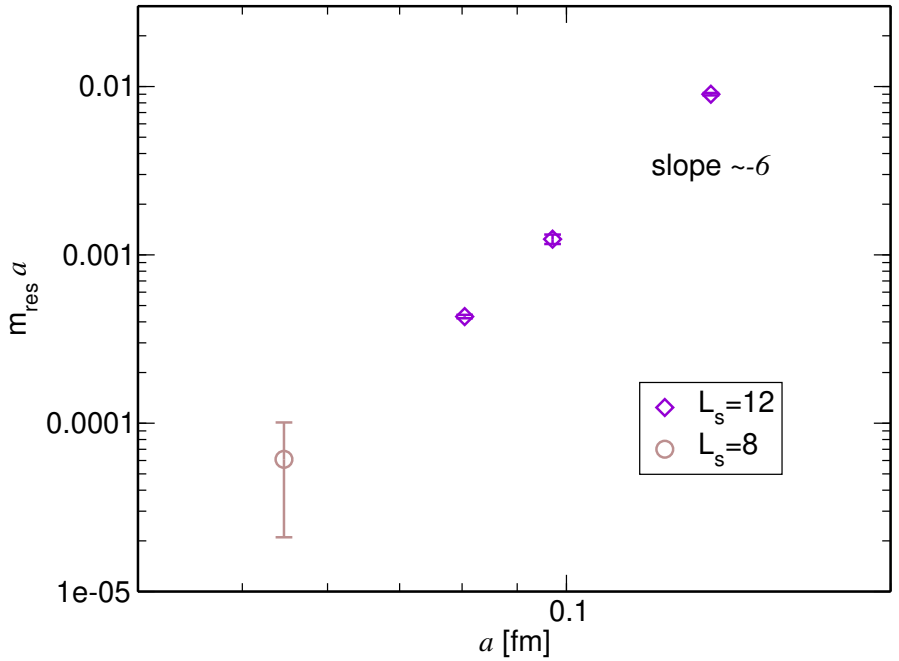
Features

- **Fine lattice: use of existing results ($0.04 \leq a \leq 0.08$ fm)**
  - Granted preciseness towards continuum limit
- **Coarse lattice parametrization is an extrapolation**
  - Preciseness might be deteriorated
  - Newly computing Z_m e.g. at $\beta = 4.0$ (lower edge) might improve, but not done so far
    - NPR of Z_m at a^{-1} ≃1.4 GeV may have sizable error (window problem) anyway
- **Smooth connection from fine to coarse should not alter leading $O(a^2)$**
  - Difference should be higher order
- **Error estimated from Kaon mass**
  - Δm_K ~ ~~10 %~~ at $\beta = 4.0$ $(a \simeq 0.14$ fm$) \rightarrow \Delta m_K$ ~ a few %
  - Δm_K ~ a few % at $\beta = 4.17$ $(a \simeq 0.08$ fm$)$

Domain wall fermions

- **Möbius DWF → OVF by reweighting**
  - Successful (w/ error growth) at $\beta = 4.17$ ($a \simeq 0.08$ fm)
    - See Lattice 2021 JLQCD (presenter: K.Suzuki)
  - Questionable for
    - Coarser lattice: rough gauge, DWF chiral symmetry breaking
    - Finer lattice: larger V (# sites)
- **Chiral fermion with continuum limit**
  - A practical choice is to stick on DWF
- **Controlling chiral symmetry breaking with DWF**
  - WTI residual mass m_{res}: $m_\pi^2 \propto (m_f + m_{res})(1 + h.o.)$
  - Understanding $m_{res}(\beta)$ with fixed L_s (5-th dim size)
- $m_{res}[MeV] \sim a^X$, **where** $X \sim 5$
  - Vanishes quickly as $a \to 0$
  - 1st (dumb) approximation: forget about m_{res}
  - Better : $m_f^{cont} \leftrightarrow (m_f + m_{res})$ but, this is not always enough



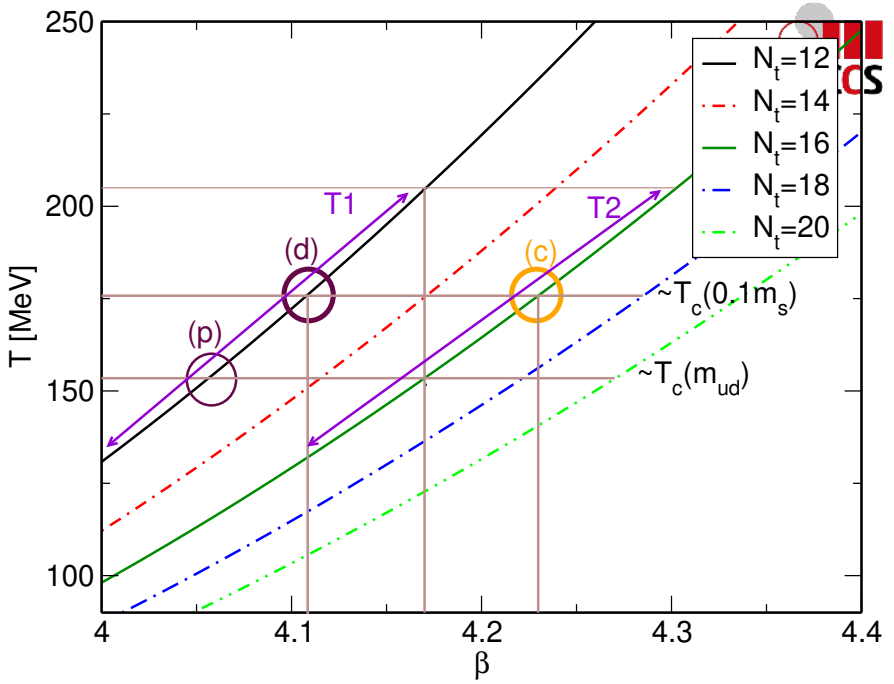


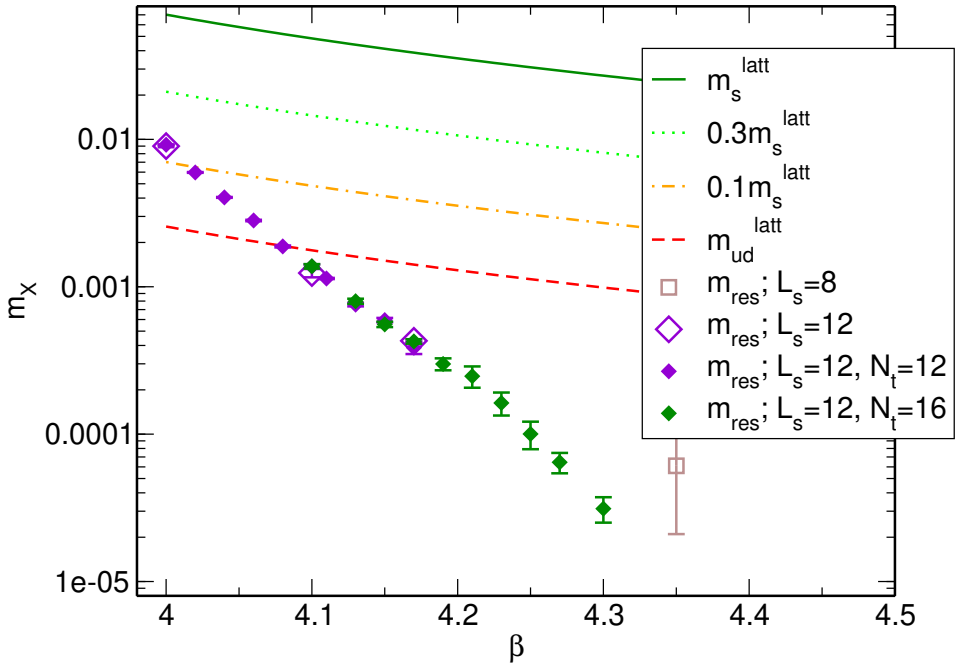
Simulation plan: 2nd round w/ treatment of m_{res} effect

$L_s = 12$ fixed throughout this study

- T1-(d)
  - $N_t = 12$
  - $m_l = 0.1m_s$
  - $m_q^{input} = m_q^{LCP} - m_{res}$
  - $V_s = 24^3$, **32^3**
- T1-(p)
  - $N_t = 12$
  - $m_l = m_{ud}$
  - $m_q^{input} = m_q^{LCP} - m_{res}$
  - $V_s = 24^3$

- T2-(c)
  - $N_t = 16$
  - $m_l = 0.1m_s$
  - m_{res} shift by reweighting
  - $V_s = 32^3$



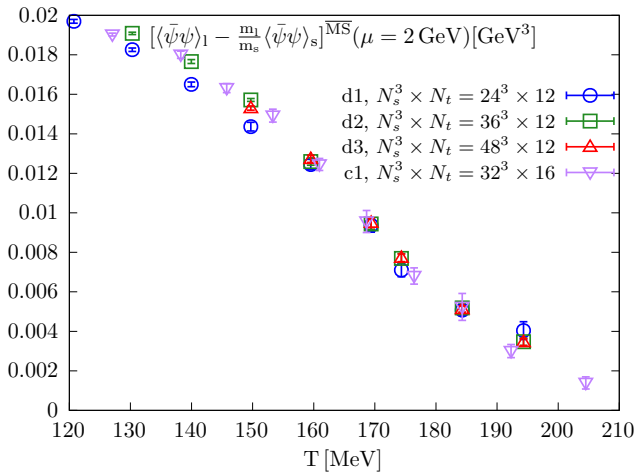


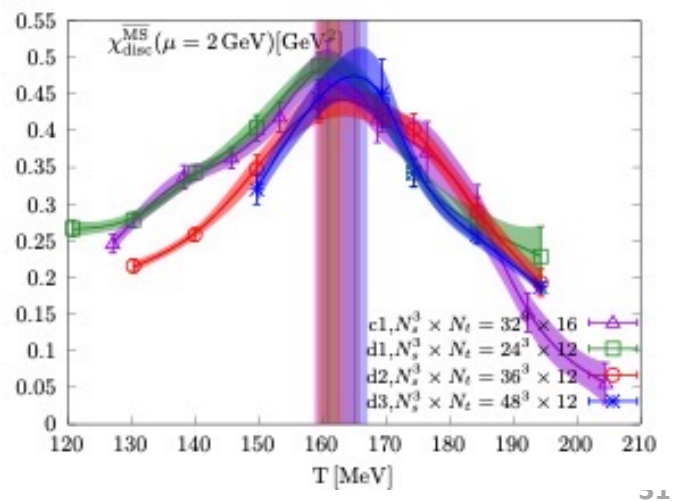
T>0 QCD using fine lattice chiral fermions

- [JLQCD] S. Aoki, Y. Aoki, H. Fukaya, J. Goswami, S. Hashimoto, I. Kanamori, T. Kaneko, Y. Nakamura, Y. Zhang,…
- R & D for the N_f=2+1 thermodynamics with Line of Constant Physics (LCP)
  - Codes: Grid, Hadrons, Bridge++
  - LCP / Reweighting
  - Chiral order parameter and renormalization
  - Quark number susceptibility



- N_f=2+1 - thermodynamics with LCP ($m_{ud} = m_s/10 \sim 3m_{ud}^{phys}$)
  - 2 step renormalization for chiral condensate (power and log divergence)
  - 2 lattice spacings N_t=12, 16
  - 3 volumes N_s/N_t=2, 3, 4
  - *No phase transition !*
  - *T_{pc} determined $T_{pc} = 165(2)$ MeV*
  - PPR-Fugaku FY2020-2022
  - [PoS Lattice 2021, 2022] / 6 invited talks
- Next : physical point FY2023-





- **Related with this project**
  - DWF thermodynamics at physical point
  - Accelerating simulation with machine learning : collaboration with **A. Tomiya**

- **one postdoc position @ R-CCS Kobe Japan is available now!**

- **please check a lattice-jobs posting early today**

my experience in this community especially Tsukuba ～ RBRC

- **I was lucky. But it's not just like that.**
- **There are people who made planning for things work like this way.**
  - So I think there are may lucky for those involved in RBRC not only myself,
  - thanks to management by good hands: TD. Lee, N. Samios, M. Ishihara, H. Enn'yo
    - to all fellow researchers for me: T. Baltz, R. Pisarski, L. McLerran, T. Izubuchi,..
    - and to administration people

  - **Now I need to start for my team to make it such an environment**
    - well I already have been trying
    - but now with these reminiscences for RBRC, I feel like really challenging.

  - **So I should always remember**
    - passions that inspire me
    - wisdoms that fascinate me
    - warmth that makes me feel at home
    - from people involved in RBRC

  - **and try put them into practice**

Congratulations RBRC for 25 years!