Experimental Approaches to Bridging Dynamics of Quark and Hadron Hierarchies

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International Symposium on

Clustering as a Window on the Hierarchical Structure of Quantum Systems

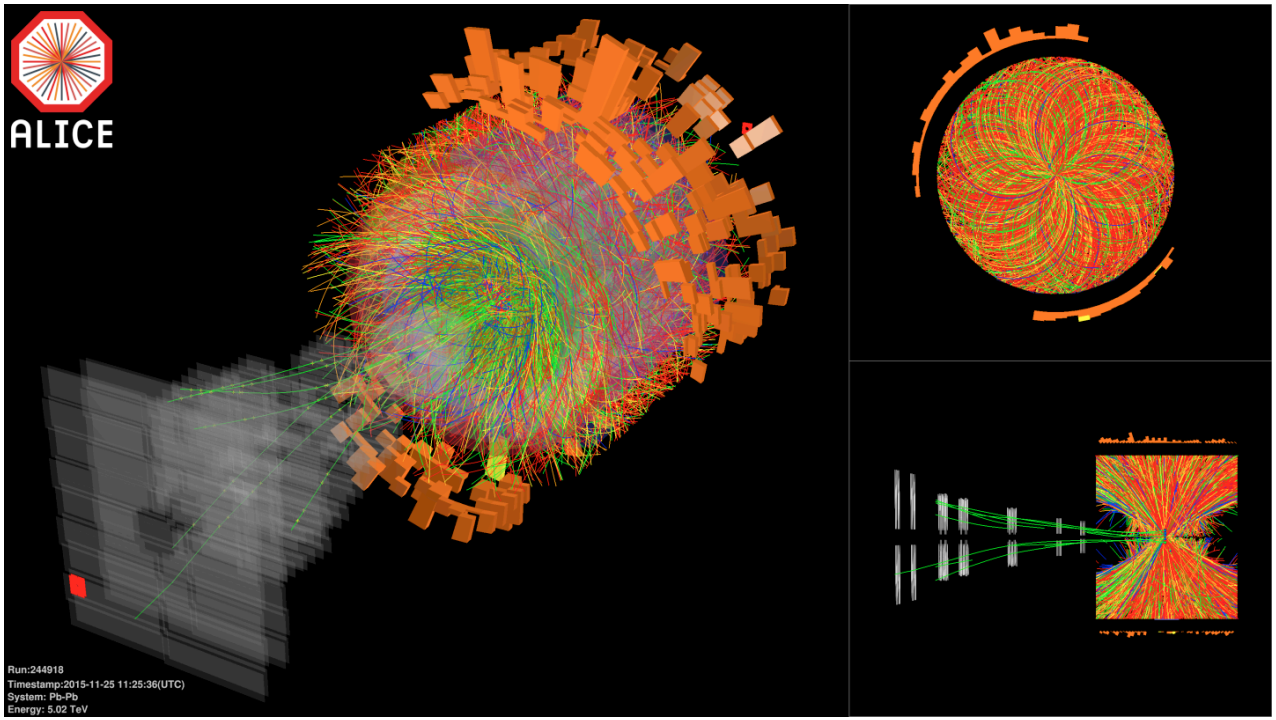
23 January 2020, Beppu, Oita, Japan

Presentation Outline

- ✔ physics via high energy nucleus collisions
  - e.g. ALICE experiment at CERN LHC
- ✔ exotic hadron and di-quark semi-hierarchy
  - physics bridging quark and hadron hierarchies
  - unique features in view of “cluster” innovative area
- experimental approaches
  - research project members
  - ALICE upgrade strategy/plan/progress/status
- possible seeds of collaboration across hierarchies
- summary and concluding remarks

Most Energetic Heavy Ion Collisions

- 5.0 TeV per nucleon-nucleon pair at CERN LHC
  - 25 times higher than at BNL RHIC in U.S.A.



- design energy at 5.5 TeV in 2021

A Large Ion Collider Experiment

- *the* nucleus-nucleus collision experiment at LHC
- 40 countries; 177 institutes; ~1,900 members

ALICE Physics Outcome at a Glance

- 254 papers on refereed journals in 10 years
  - as of beginning of this week
  - including 2 Nature Physics, 81 PLB, 34 PRL
  - 36 in last 12 months

- deconfined quark behavior in strong QCD field
- quarks interaction in strong QCD field
- QGP-like signatures in high-multiplicity *p*-*p*, *p*-Pb
- more exotic physics
  - *e.g.* chiral anomaly effects
    - ultra-intense vorticity and magnetic field

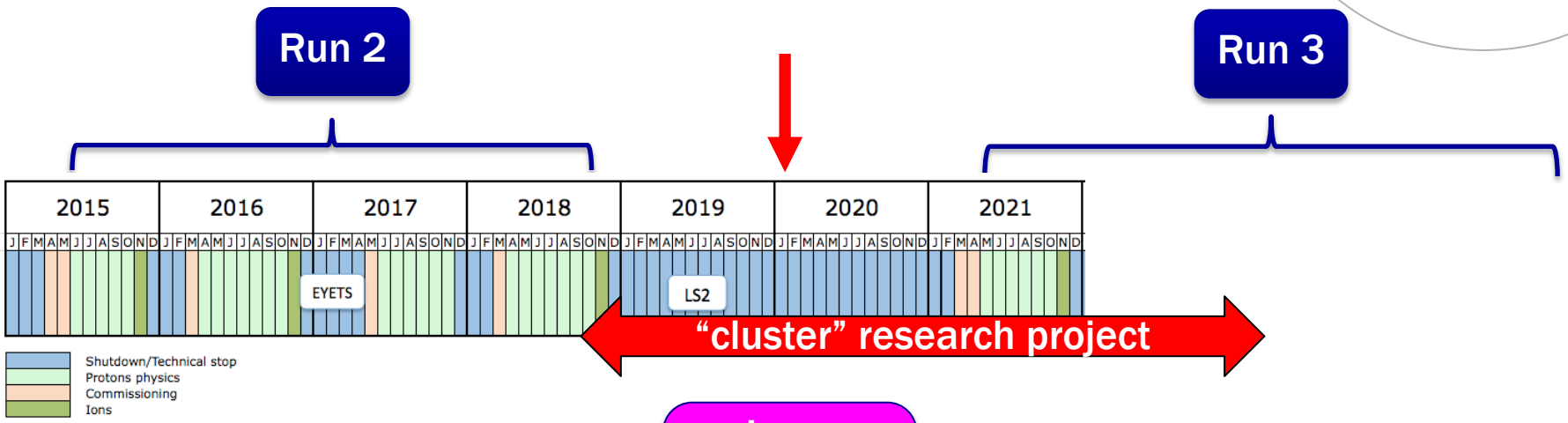
“Our” Presence in ALICE

- as of today (not inclusive)
  - collaboration board deputy chair (Oyama)
  - run coordinator (Gunji)
  - jet physics working group co-convener (Chujo)
  - EM calorimeter deputy project leader (Chujo)
  - muon forward tracker control/service work package co-convener (Shigaki)
- in the past (major ones only)
  - collaboration board deputy chair (Hamagaki)
  - low mass di-electron physics analysis group co-convener (Gunji)

Research Project Members

- principal investigator **Kenta SHIGAKI (Hiroshima)**
- project PD **Yorito YAMAGUCHI (Hiroshima)**
  - new forward tracking detector
- co-investigator **Hideki HAMAGAKI (Nagasaki IAS)**
  - data handling scheme upgrade
- co-investigator **Tatsuya CHUJO (Tsukuba)**
  - grid computing core facility
- co-investigator **Taku GUNJI (Tokyo)**
  - main tracking detector upgrade
- research collaborator **Maya SHIMOMURA (Nara Women's)**
  - conducting experiment, physics analysis

Where We Are at LHC



6.5 TeV proton beam
p-*p*, *p*-Pb, Pb-Pb

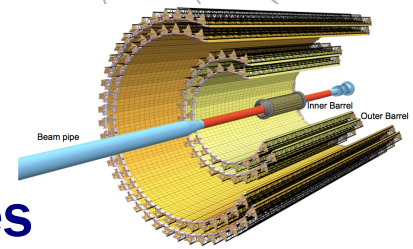
Long Shutdown 2

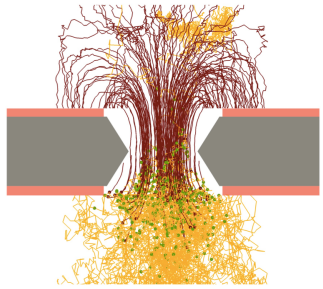
7.0 TeV proton beam
p-*p*, *p*-Pb, Pb-Pb

LHC luminosity upgrade
ALICE upgrade & speeding up

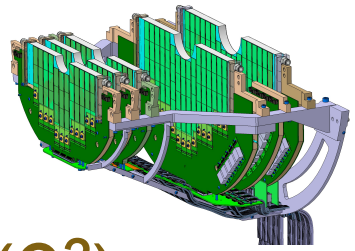
Upgrades for Run 3 (2021–2024)

- new inner tracking system
  - 7 layers of MAPS silicon pixel detectors
  - precise measurement of displaced vertices
    - to separate charm/beauty mesons





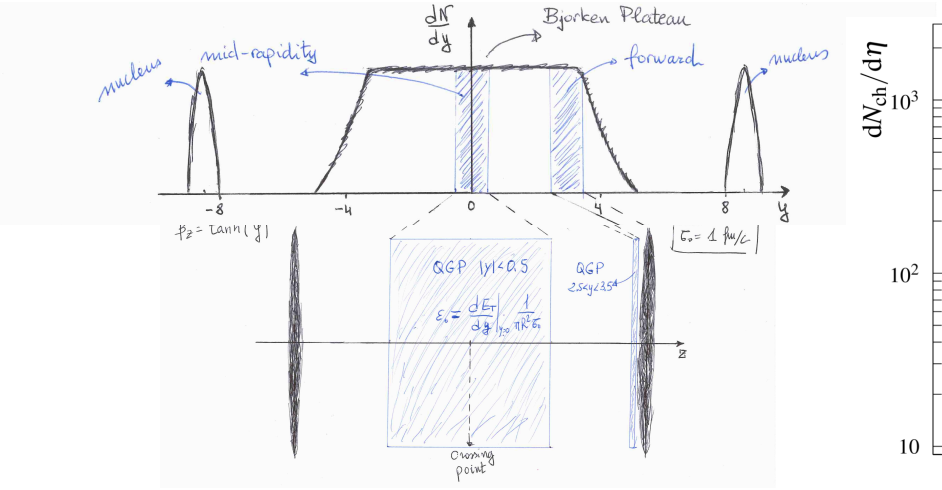
- new TPC readout chambers
  - GEM technology with no gating grid
  - ~100 times higher data taking rate (50 kHz in Pb-Pb)
    - continuous readout without triggering

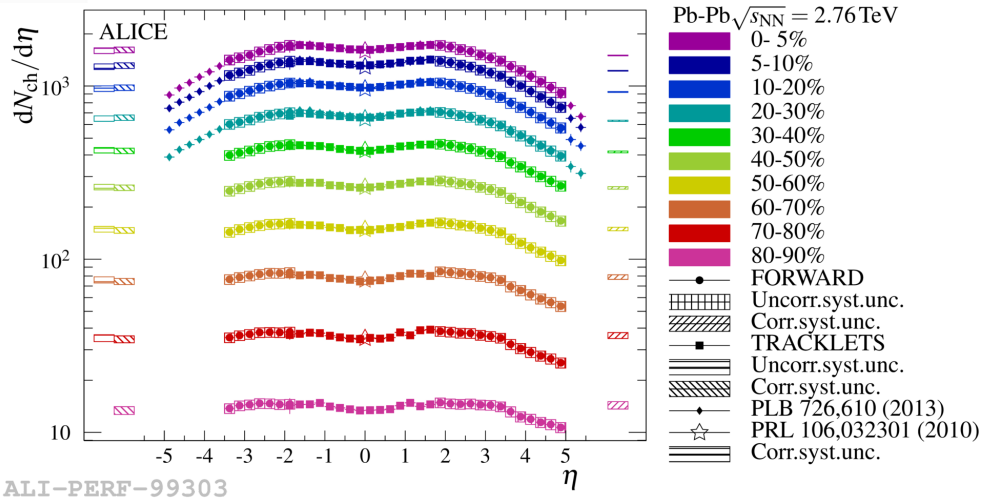


- Muon Forward Tracker (MFT)
- integrated online/offline data handling (O^2)

Aufheben of e + μ Measurements

- two interesting regimes of quark-gluon phase
  - exploration on QCD phase diagram

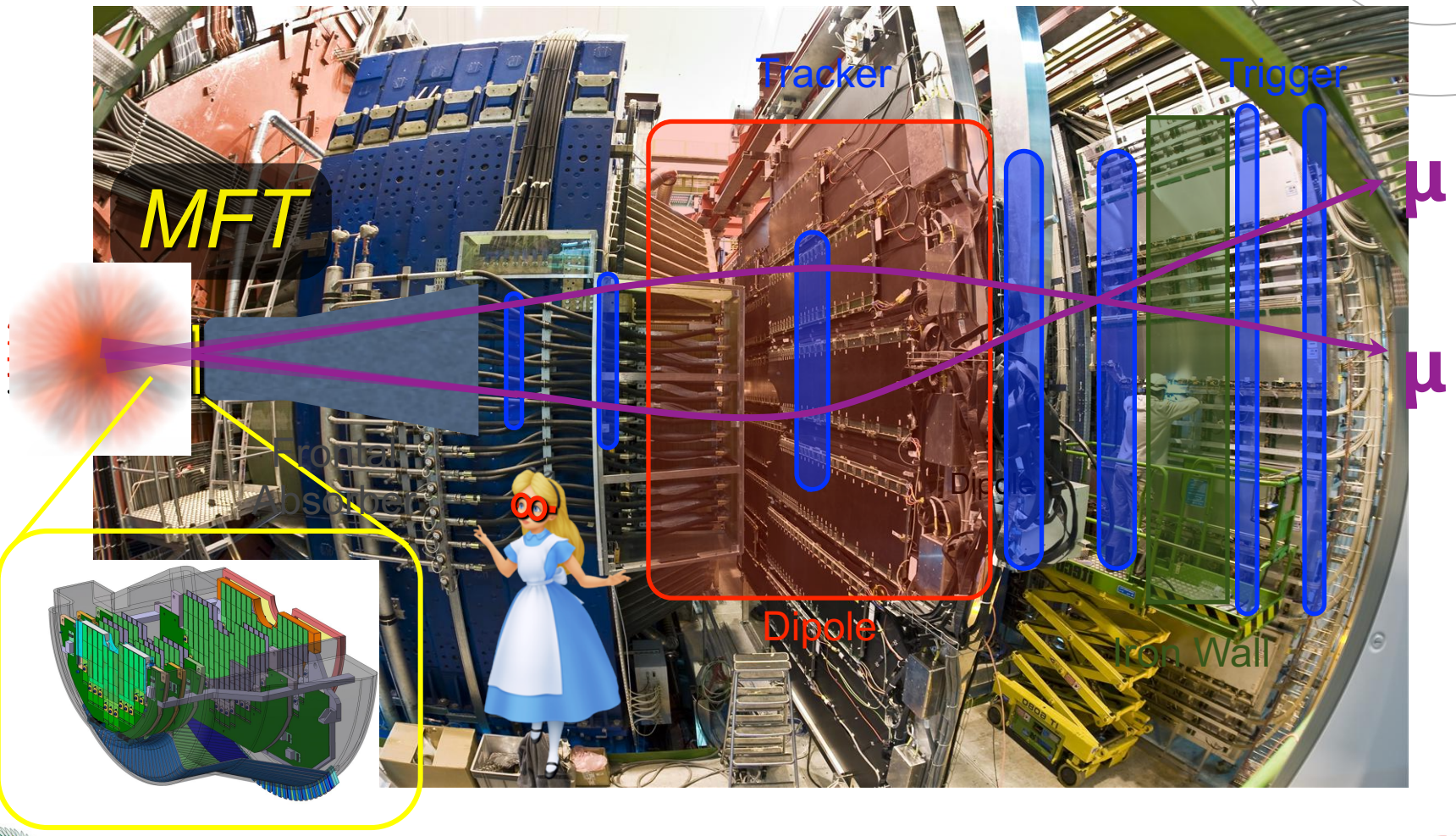




- new opportunity via muons at LHC (and above)
  - *not too forward* for "central" physics
  - technically *forward enough* for muon measurement

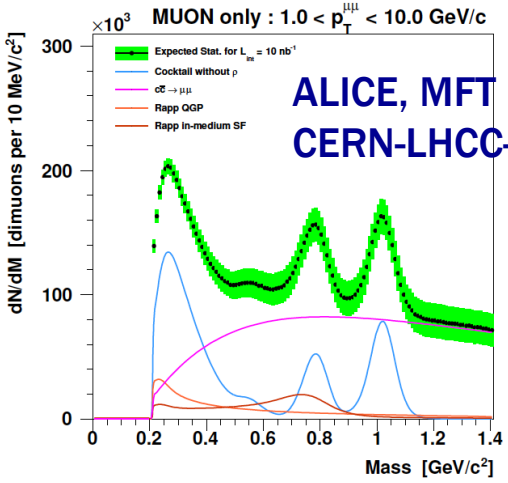
Muon Forward Tracker (2021–)

- precise vertex and invariant mass measurements

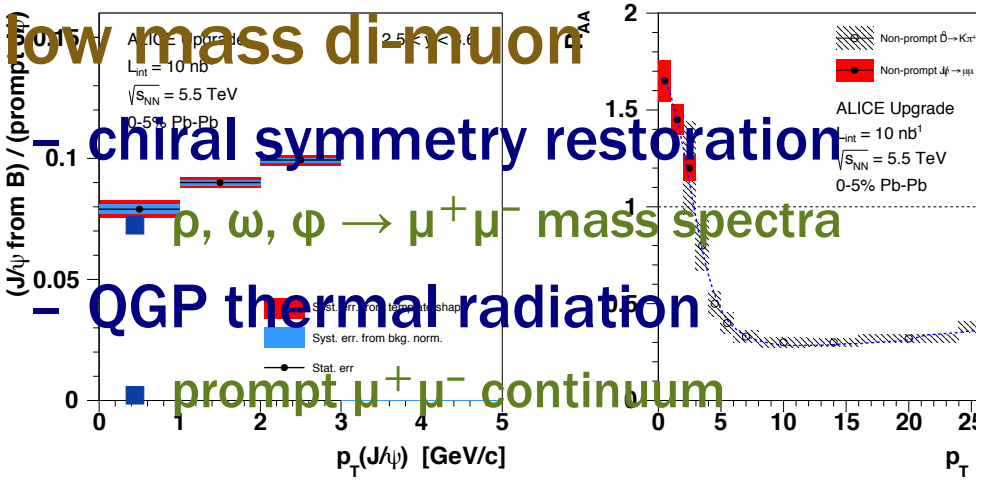


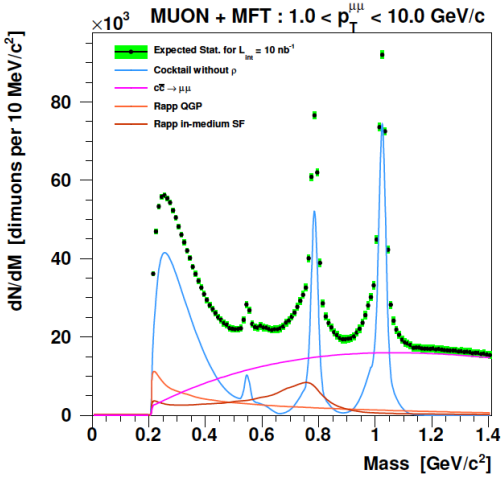
MFT Physics Goals at a Glance

- **separated open heavy flavors**
  - D → μ p_T > 0–1 GeV/c
  - B → μ p_T > 2 GeV/c
  - J/ψ p_T > 0 GeV/c
- **separated quarkonia**
  - prompt/secondary J/ψ, ψ(2S), Υ(1S/2S/3S)
- **low mass di-muon**
  - chiral symmetry restoration
    - ρ, ω, φ → $\mu^+\mu^-$ mass spectra
  - QGP thermal radiation
    - prompt $\mu^+\mu^-$ continuum



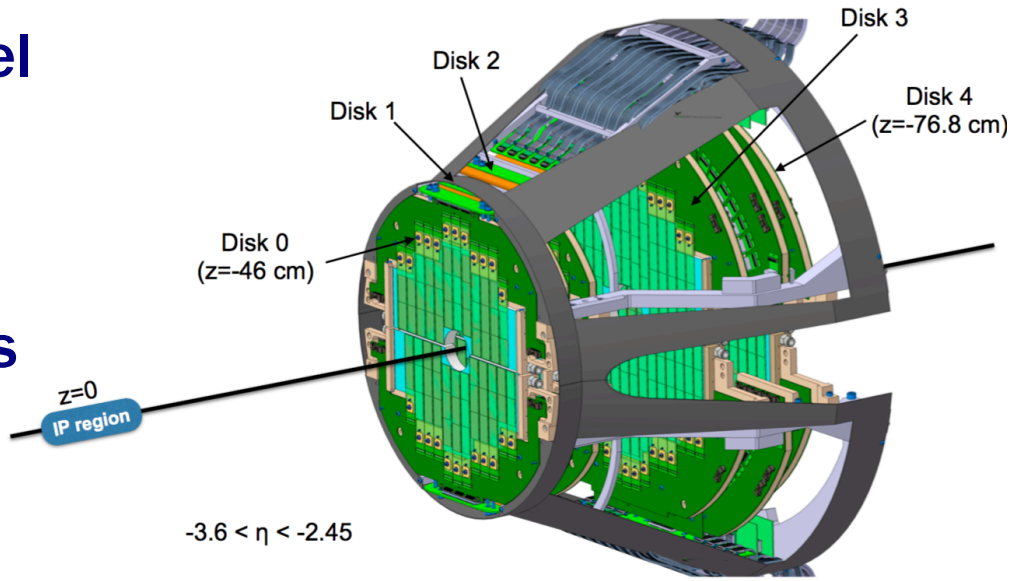
ALICE, MFT LOI, CERN-LHCC-2013-014





Muon Forward Tracker Design

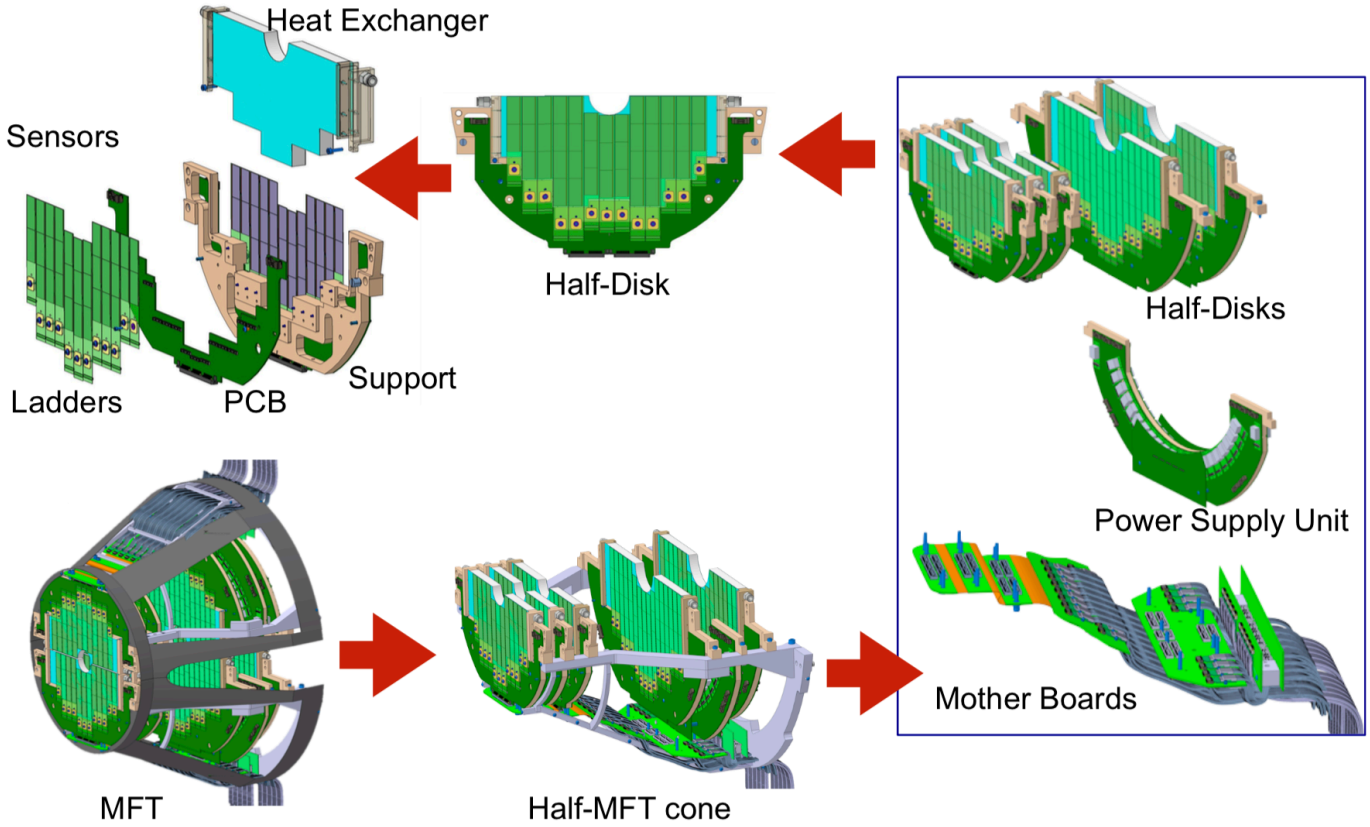
- $2.45 < -\eta < 3.6$
  - $-z = 460-768$ mm
- 0.4 m^2 of MAPS silicon pixel sensors
  - 28 μm × 28 μm pixel
  - 0.35% X_0 per layer
- 10 sensitive layers
  - 5 double sided disks



- precise vertexing capability for forward muons
- Pb-Pb ~50 kHz, *p*-*p* ~200 kHz

MFT Structure and Elements

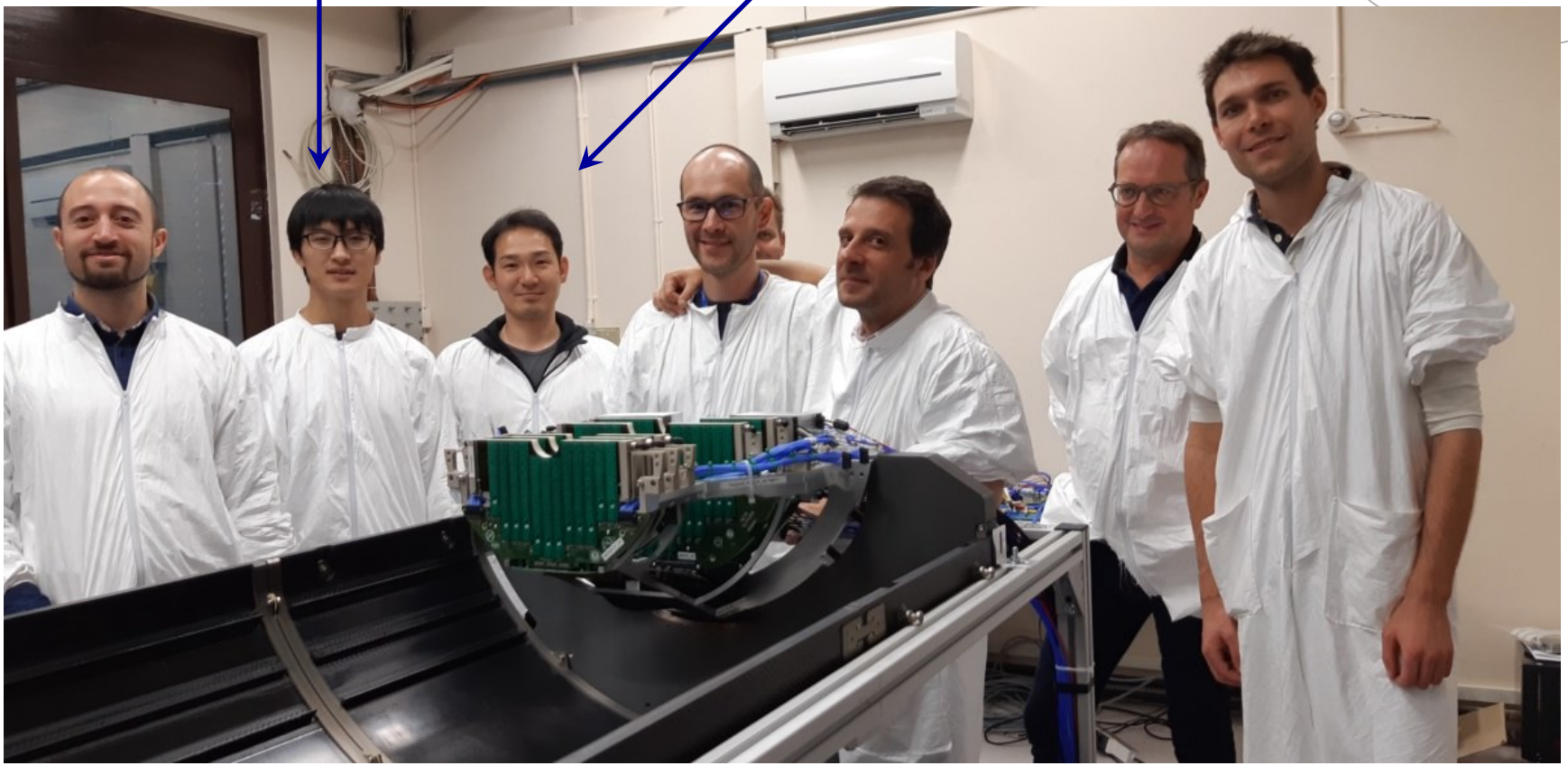
- chip (936)/ladder (280)/zone (80)/half plane (20) /half disk (10) + PS unit (2)/half MFT (2)/MFT (1)



First Half MFT Assembly in 2019/10

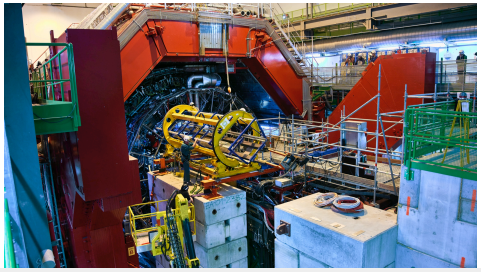
Motomi Oya (HU grad. student)

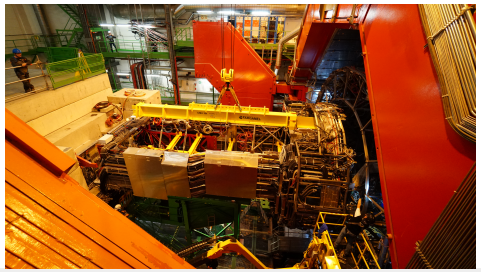
Yorito Yamaguchi (HU PD)



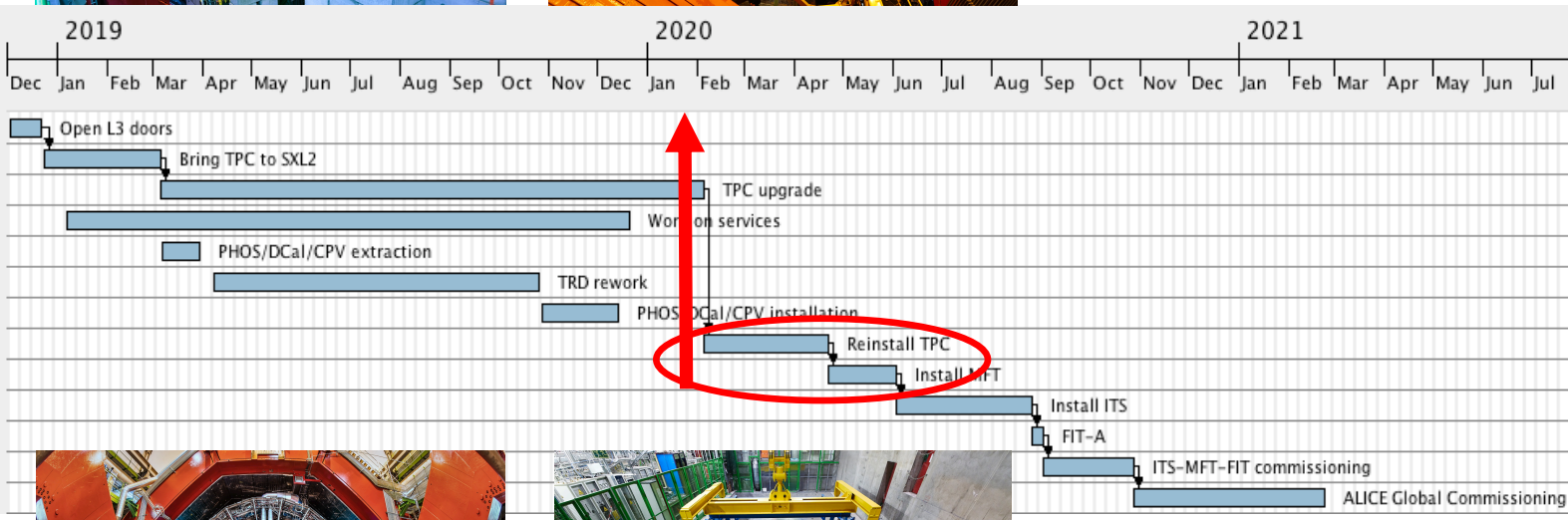
Upgrade Schedule in (2019–) 2020

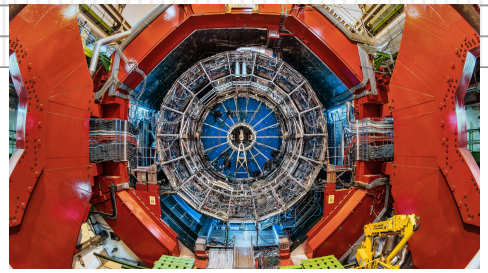
- detector components removed and coming back

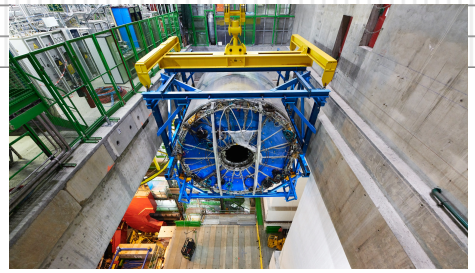




Begin date	End date	Duration
3/12/18	21/12/18	15
24/12/18	5/3/19	52
6/3/19	4/2/20	240
7/1/19	20/12/19	250
7/3/19	29/3/19	17
8/4/19	25/10/19	145
28/10/19	13/12/19	35
5/2/20	21/4/20	55
22/4/20	2/6/20	30
3/6/20	25/8/20	60
26/8/20	1/9/20	5
2/9/20	27/10/20	40
28/10/20	22/2/21	84

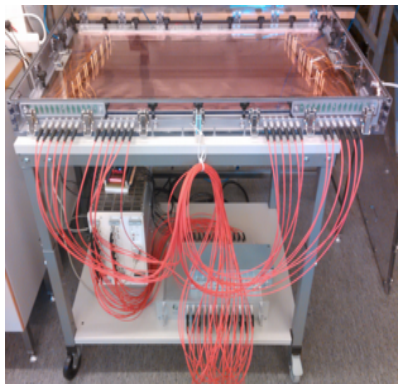


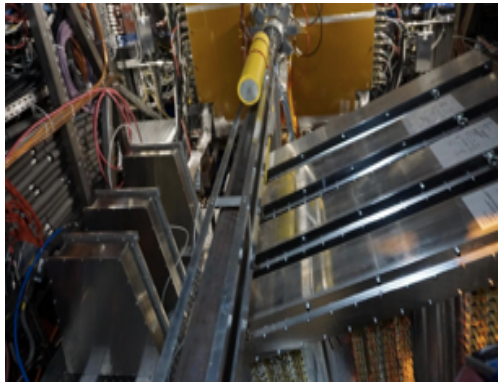
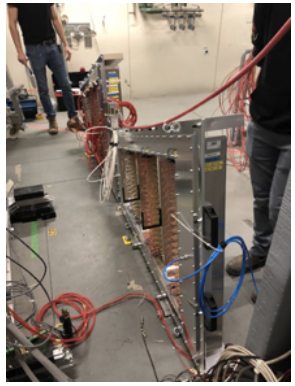




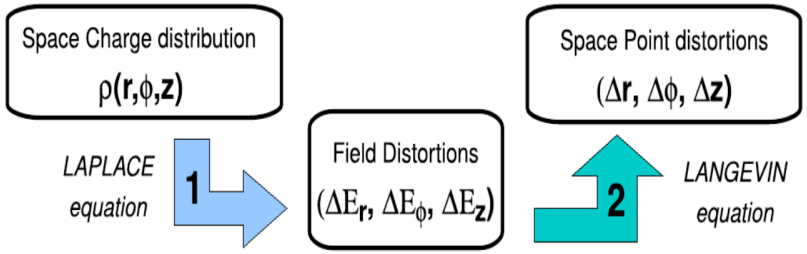
Quick Look at Other Activities (1)

- new GEM for time projection chamber upgrade
  - installed after quality assurance and tests on site



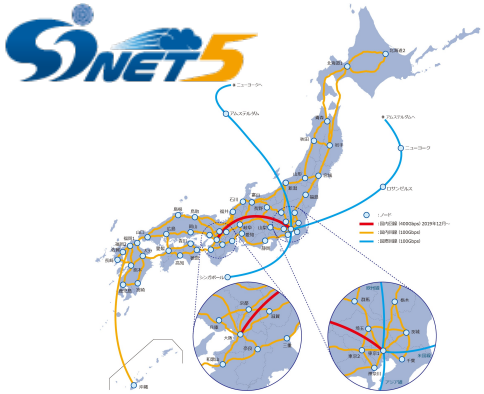



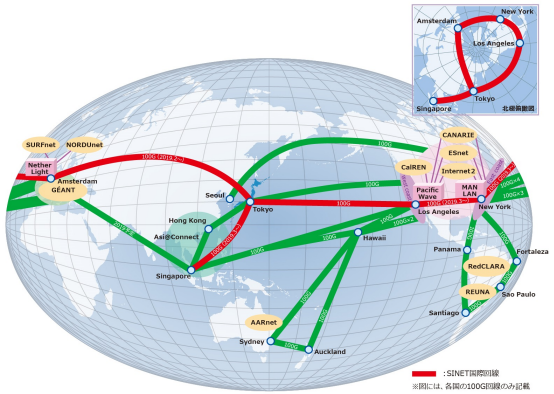

  - study for online space charge effect correction
    - machine learning on GPU



Quick Look at Other Activities (2)

- ALICE computing grid Tier 2 at U. Tsukuba
  - to secure/enhance computing resource in Japan
    - toward run 3 (2021–)
  - 2019
    - 168 TB RAID added as a part of this research project
    - 10 Gbps fiber connection to SINET5 via Hepnet-J





  - more worker nodes, storage, band width

Across-Hierarchies Research Seeds

- exotic hadrons (and di-quark semi-hierarchy)
  - w/ theory group
  - *cf.* previous presentation by H. Hamagaki
  - high prospect in ALICE Run 3 from 2021/05
- hadronization mechanism; Y-N, Y-Y interaction
  - w/ nuclear physics experiment and theory groups
- perfect fluidity (discovered at RHIC)
  - w/ cold atom experiment groups
    - long standing dream, but little actual collaboration so far
  - workshops planned in 2020
    - more ideas, *e.g.* few body system production mechanism

Summary and Concluding Remarks

- deconfined quarks: most fundamental hierarchy
  - only by high energy nucleus-nucleus collisions
  - relevant to early universe evolution
- unique dynamics bridging quark–hadron hierarchies
  - quark coalescence (*cf.* color string fragmentation)
- ALICE at LHC exploring quark physics frontier
- preparation at peak toward upgraded runs (2021–)
  - x 100 higher rate for rare/hard-to-catch phenomena
- seeking new collaborative research possibilities
  - workshops planned in 2020; please join us!