Dilepton Measurements
and
Chiral Symmetry Restoration
at
LHC and Elsewhere

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Extended 36th Heavy Ion Cafe

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Sophia University

Presentation Outline

- multiple physics motivations
- high mass results
- intermediate mass results and challenges
- low mass results and outlook
  - LHC (w.r.t. RHIC)
    - with my personal belief in dimuons at LHC (ALICE)
  - J-PARC E16
- summary and concluding remarks

Multiple Physics Motivations

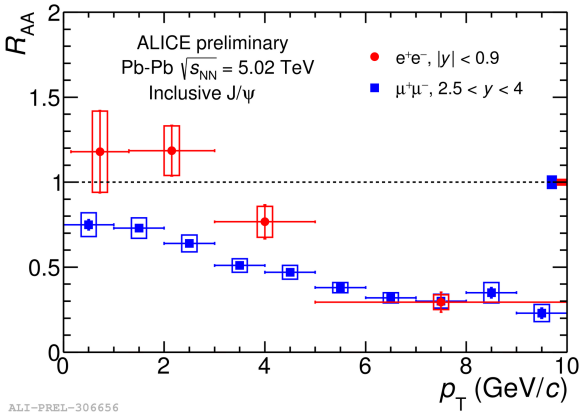
- high mass（J/ψ and above）
  - color Debye screening
  - sequential melting thermometer
  - heavy quark thermalization
- intermediate mass (between φ and J/ψ）
  - heavy flavor production
  - thermal radiation
- low mass (up to φ)
  - chiral symmetry restoration
  - thermal radiation

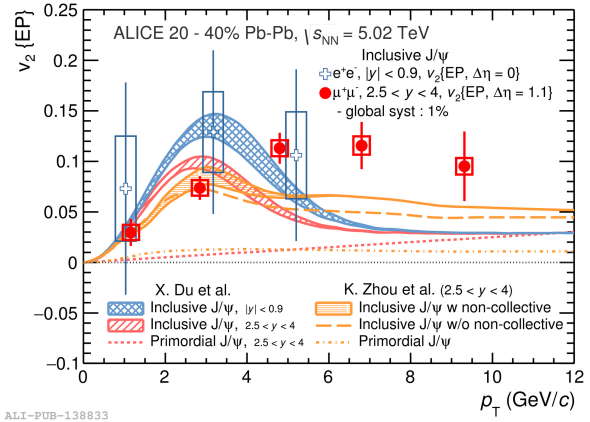
famous though infamous channel

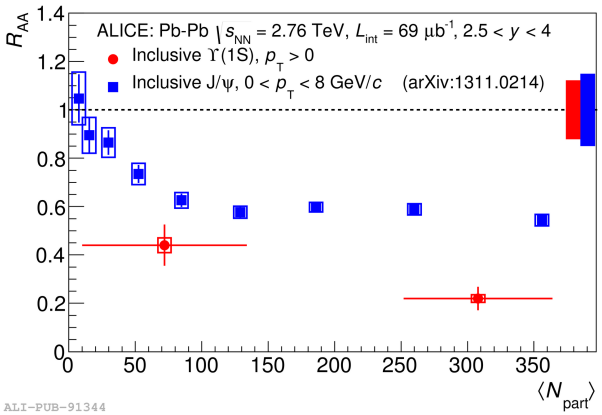
- yes, di-leptons are clean and attractive
  - famous penetrating probe
  - physics already discussed by M. Kitazawa
- but, di-leptons are challenging
  - infamously rare signal; high BG; technical issues
- only cases worth the challenge (personal view):
  - low mass low p_T physics to look into early stage
  - high mass vector mesons in clean decay channels
    - → T. Gunji, heavy flavor
  - (good) substitute for real photons
    - *ref.* T. Sakaguchi, photons

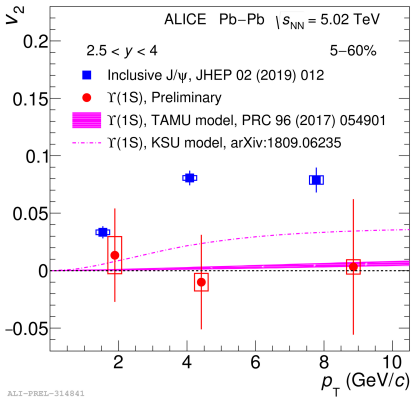
Ultra Summary of High Mass Results

- J/ψ suppressed, regenerated and collective
- Υ suppressed, less regenerated or collective



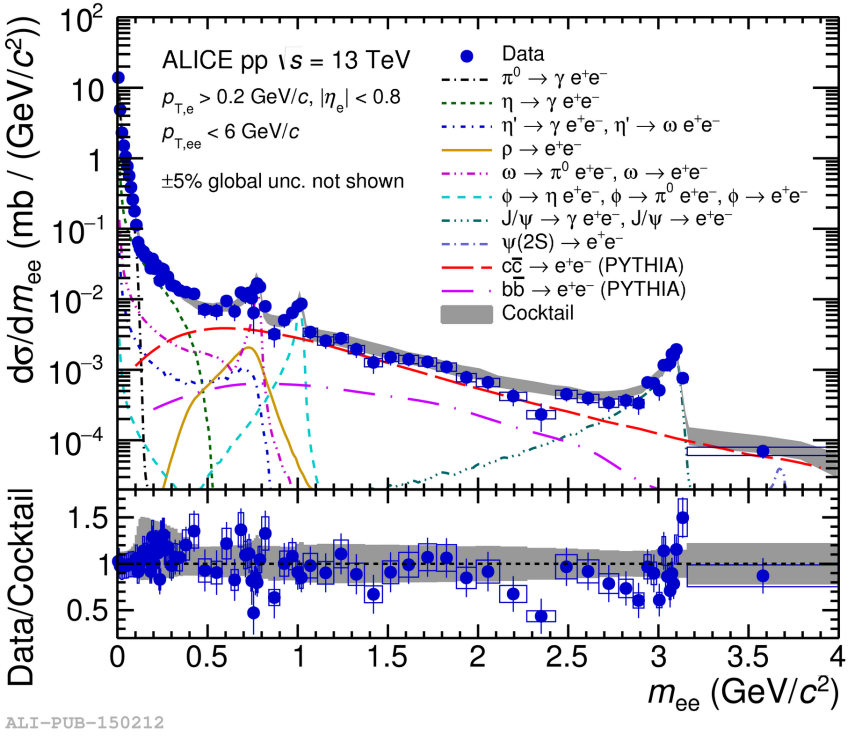


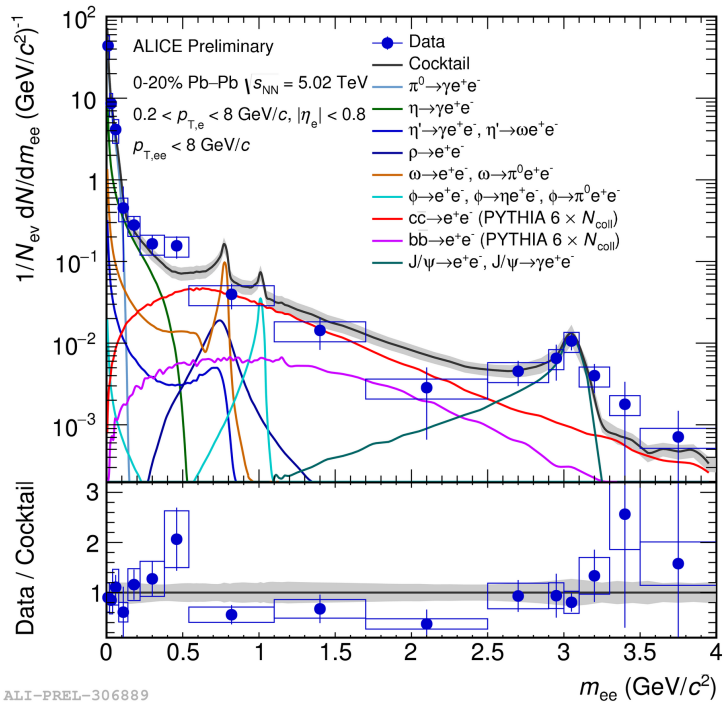




Low/Inter. Mass Dielectrons at ALICE

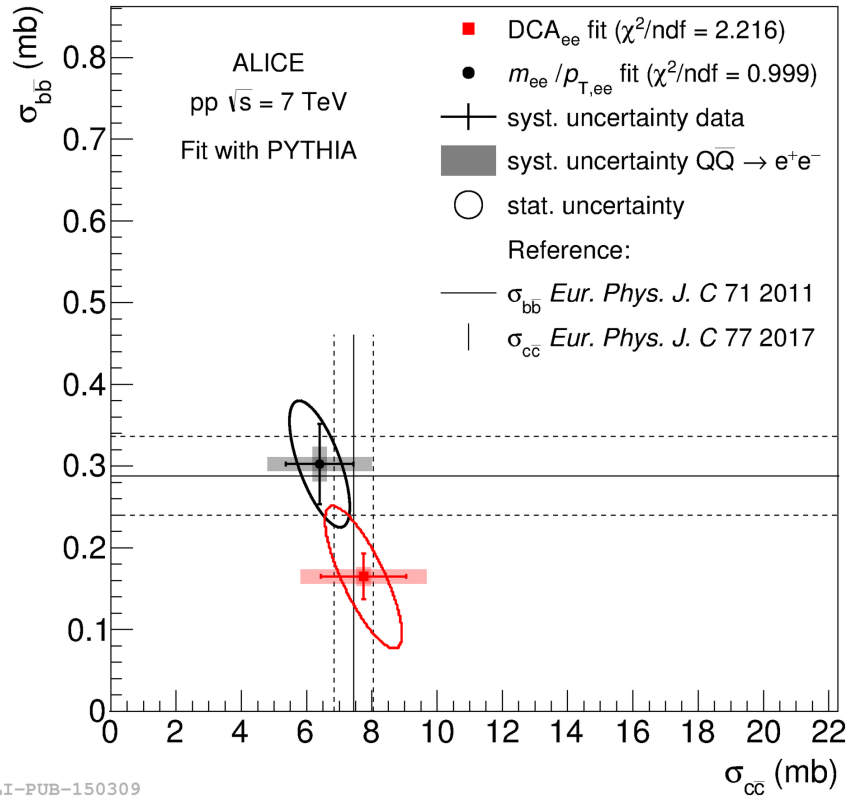
- leading effort by Taku Gunji
  - former low mass dielectron PAG co-coordinator





Intermediate Mass Physics

- charm and beauty production
  - yet with large model dependence



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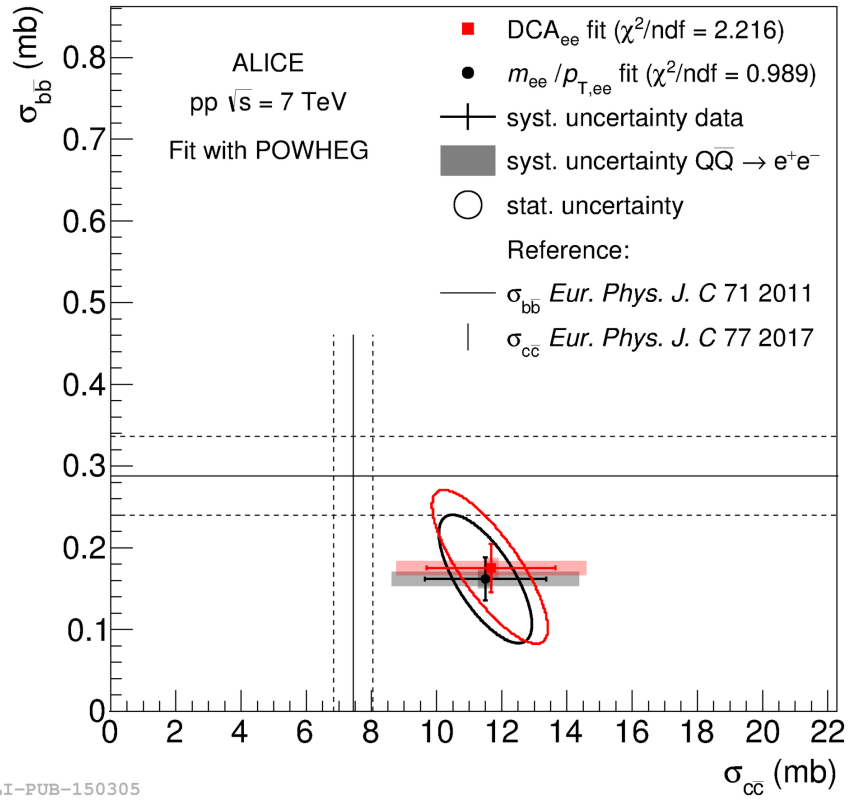

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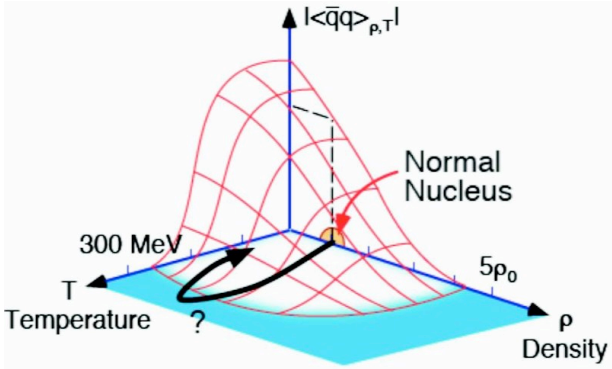
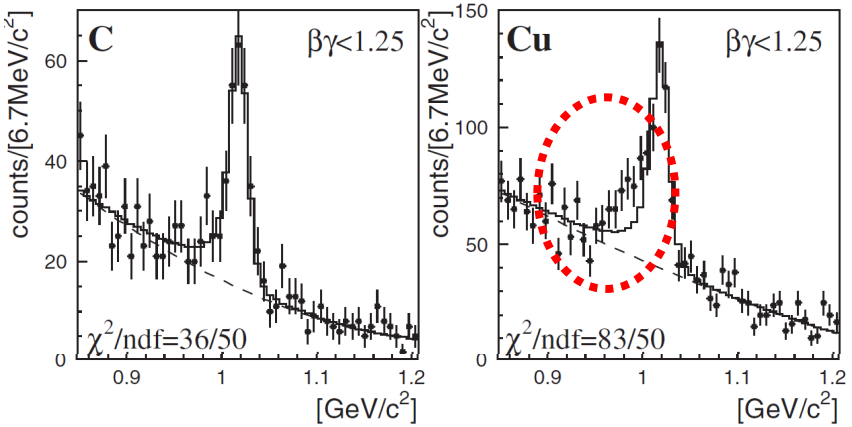
Low Mass Low p_T Physics

- chiral symmetry restoration
- "observed" in finite density regime
  - φ, ω in nuclei via *p*-A (KEK E325)
    - though apparent contradiction to CB-ELSA/TAPS and CLAS-G7
  - π in nuclei via (*d*, ^{3}He)



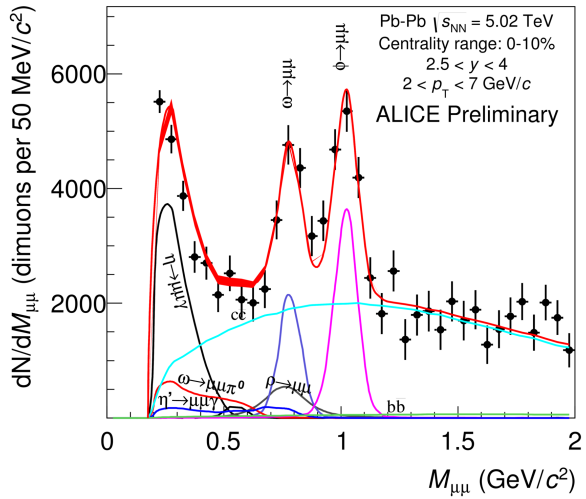


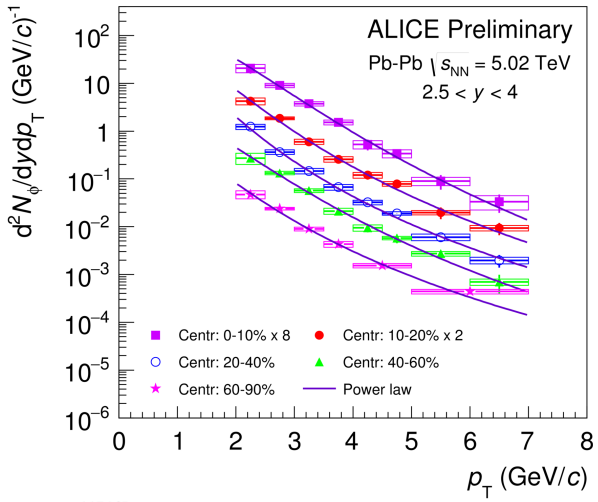
R. Muto *et al.*, Phys. Rev. Lett. 98, 042501

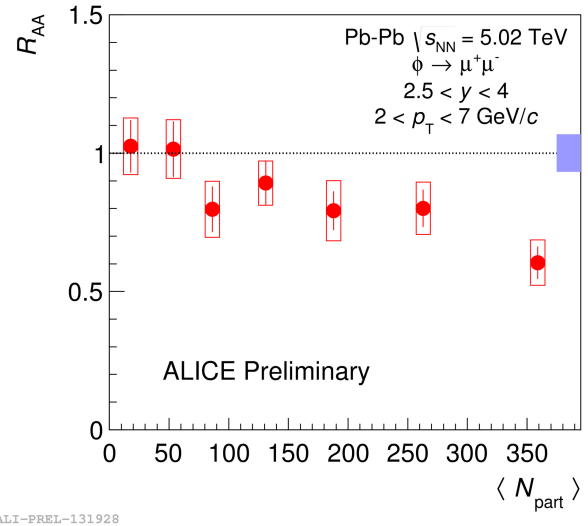
- no evidence in high temperature regime yet
  - dilepton measurements very challenging

Low Mass Dimuons at ALICE

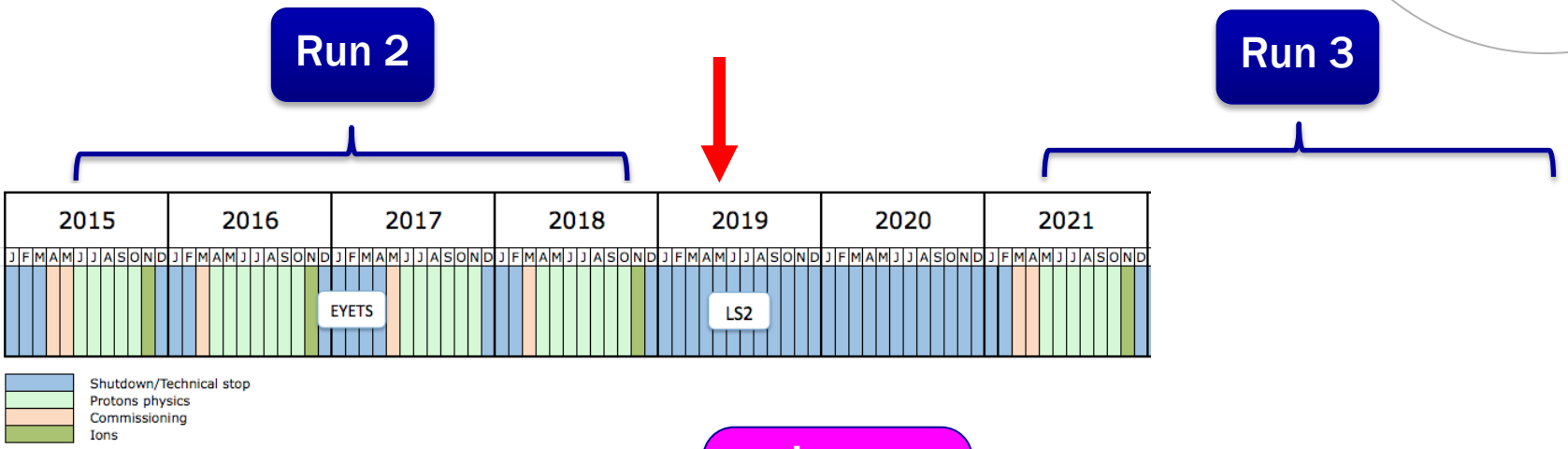
- clean φ and ω mass spectra in central Pb+Pb
- ρ depending on charm “background”
  - charm interesting by itself
- key: low p_T reach







Improvement Coming Soon



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

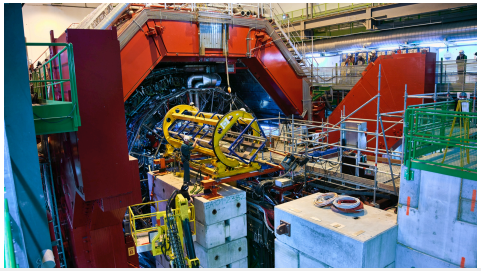
Long Shutdown 2

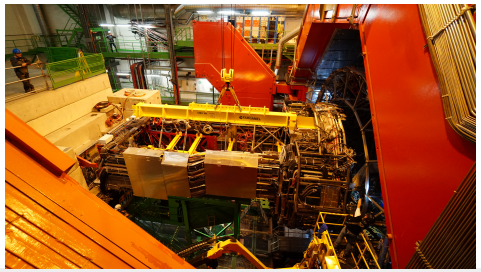
7.0 TeV proton beam
p-*p*, *p*-Pb, Pb-Pb

LHC luminosity upgrade
ALICE upgrade & speeding up

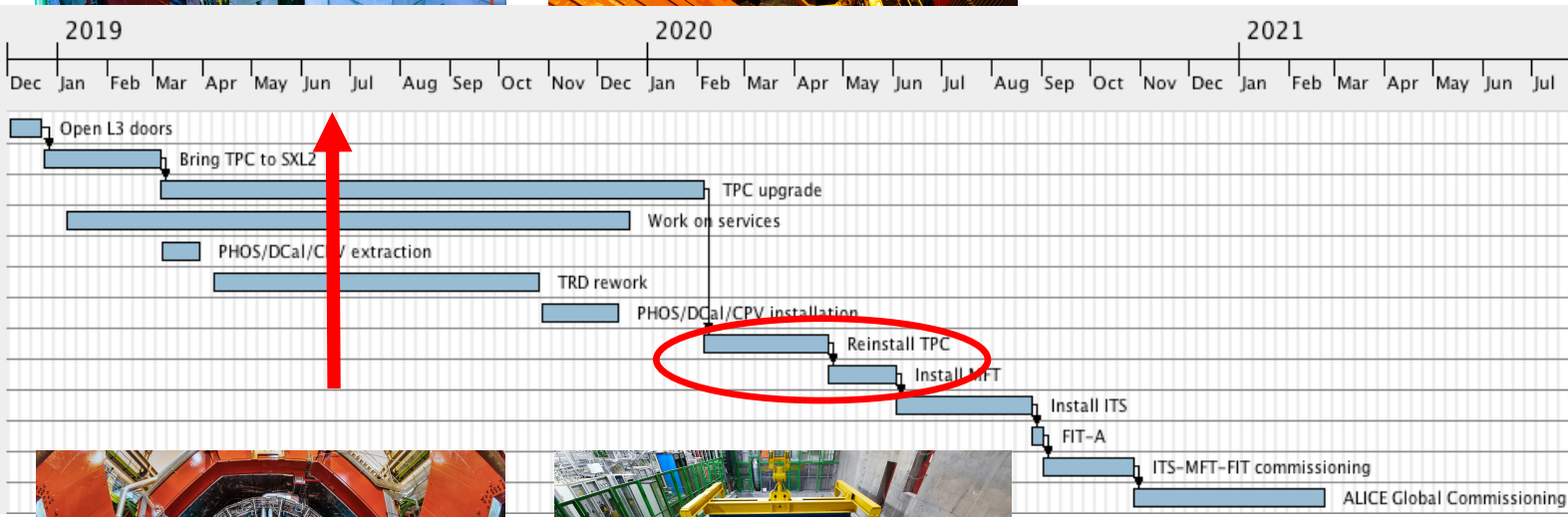
Upgrade Schedule in 2019–2020

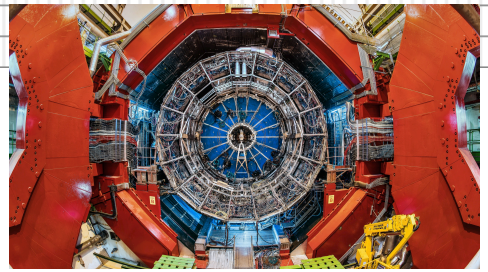
- detector components already removed

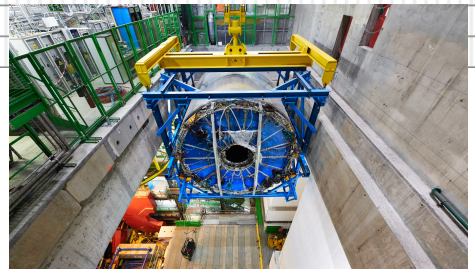




Begin date	End date	Duration
3/12/18	21/12/18	15
24/12/18	5/3/19	52
6/3/19	4/2/20	240
7/1/19	20/12/19	250
7/3/19	29/3/19	17
8/4/19	25/10/19	145
28/10/19	13/12/19	35
5/2/20	21/4/20	55
22/4/20	2/6/20	30
3/6/20	25/8/20	60
26/8/20	1/9/20	5
2/9/20	27/10/20	40
28/10/20	22/2/21	84





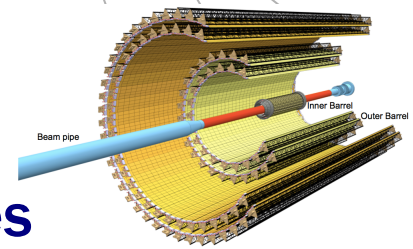


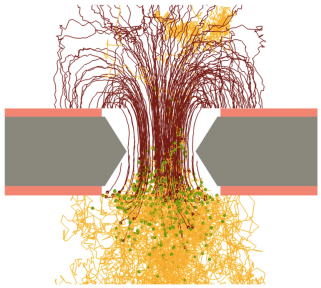
ALICE Upgrade Strategies

- 1st – high p_T phenomena (jets), heavy flavors
  - ✓ × 2–3 speeding up, new detectors; LS1 2013–2014
- 2nd – low/mid p_T phenomena, e.g. c, b ≥ 0 GeV/c
  - × 100 speeding up, new detectors; LS2 2019–2020
    - new vertex trackers
    - new TPC end cap chamber (Tokyo)
    - new muon forward tracker (Hiroshima + Nara, Nagasaki)
    - new integrated online/offline handling (Nagasaki + JAEA)
- 3rd – t.b.d.: (further) forward physics?
  - new detectors; LS3? 2024?
    - new forward calorimeter (Tsukuba + Nara, Hiroshima) ?

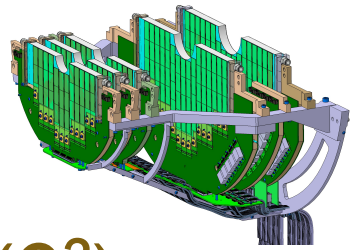
Major Upgrades for Run 3 (2021–)

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





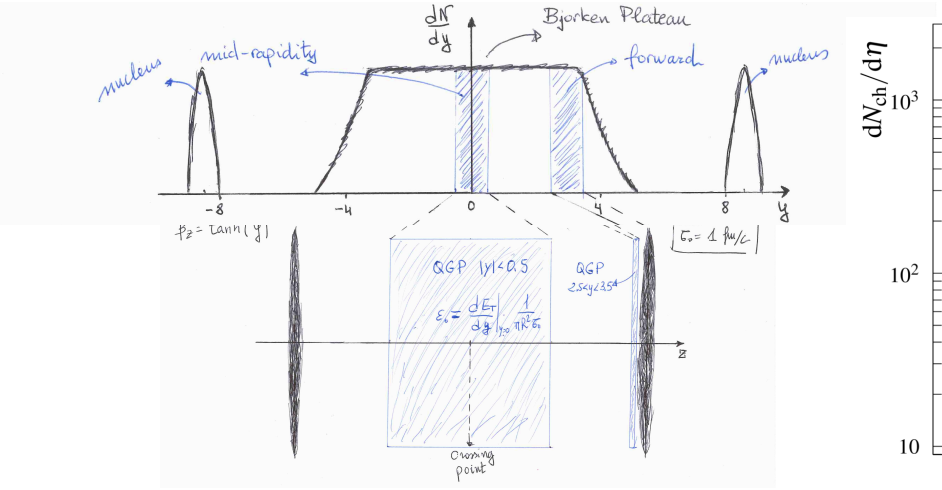
- new TPC readout chambers
  - GEM technology with no gating grid
  - ~100 times higher data taking rate (50 kHz in Pb-Pb)
    - continuous readout without triggering

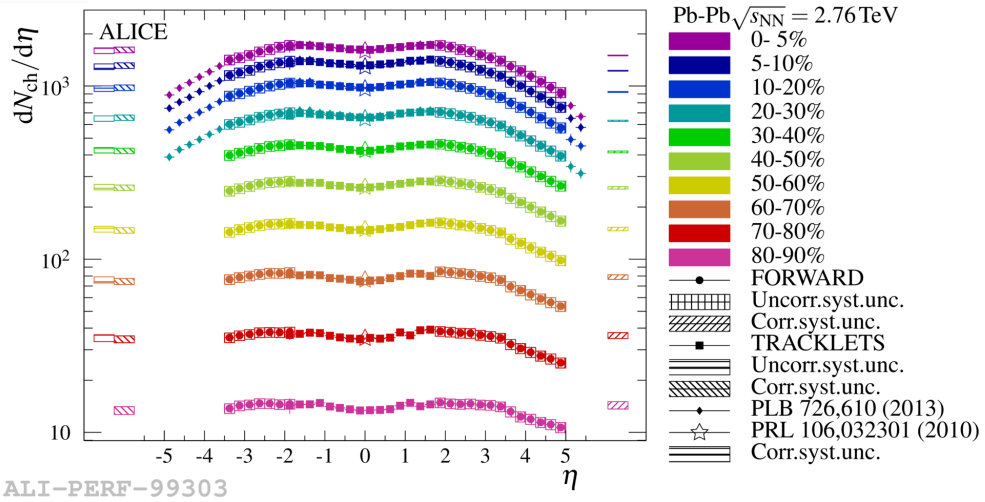


- Muon Forward Tracker (MFT)
- integrated online/offline data handling (O^2)

Aufheben of e + μ Measurements

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

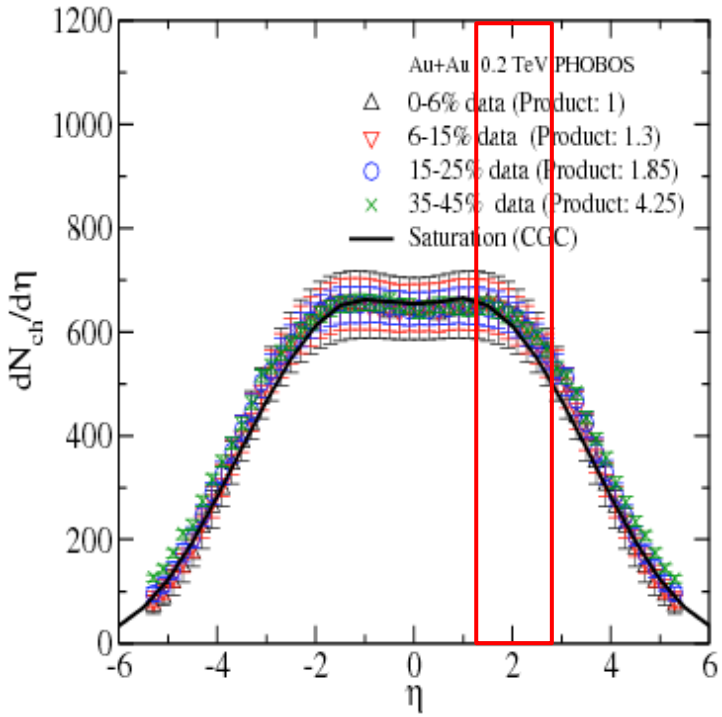


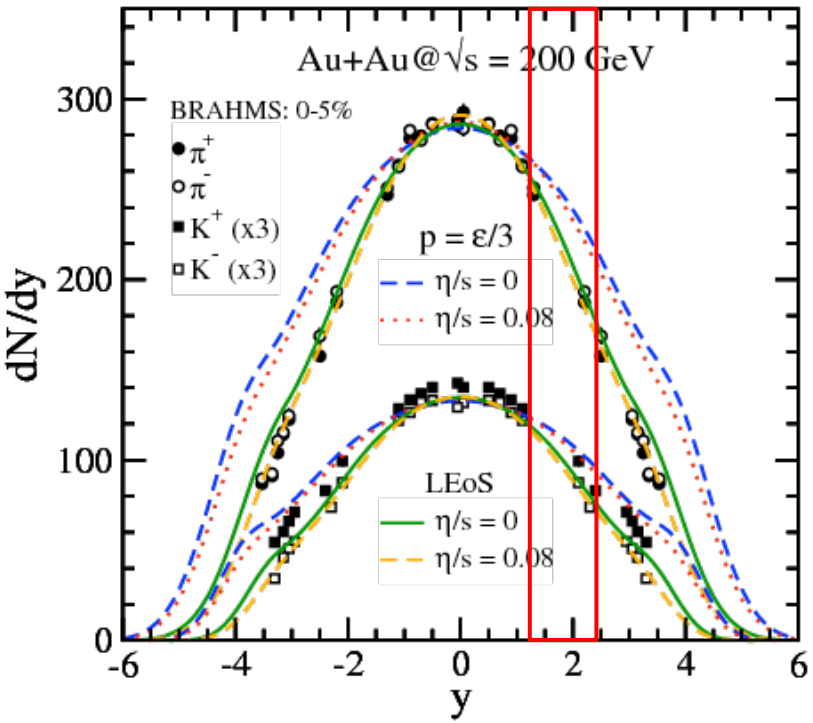


- new opportunity via muons at LHC (and above)
  - *not too forward* for "central" physics
  - technically *forward enough* for muon measurement

Muon Measurement at RHIC-PHENIX

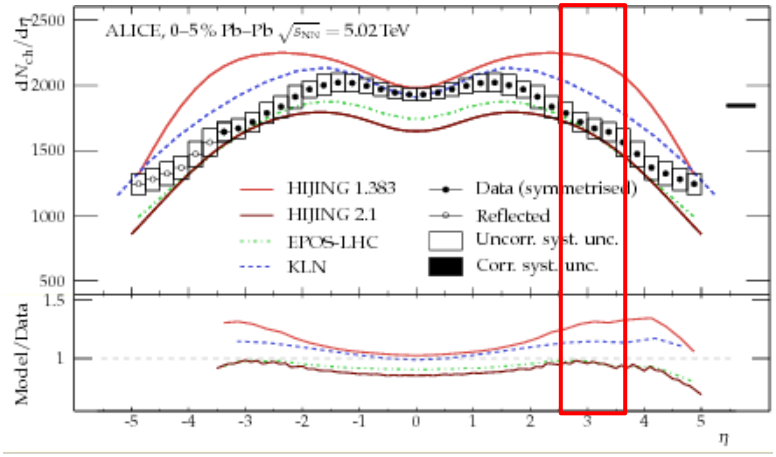
- muon arms: $1.2 < |\eta| < 2.4$
  - shoulder of central rapidity plateau
- minimum p_T ~ 1.0 - 1.5 GeV/c

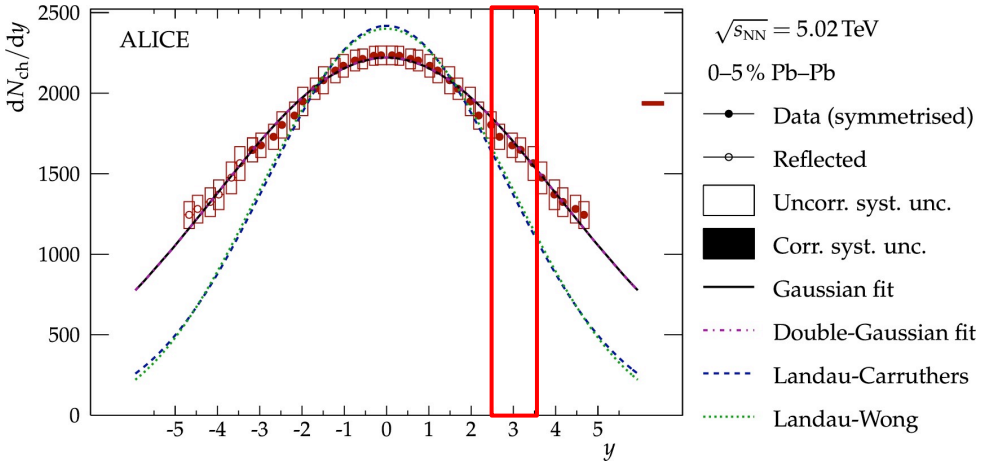




Muon Measurement at LHC-ALICE

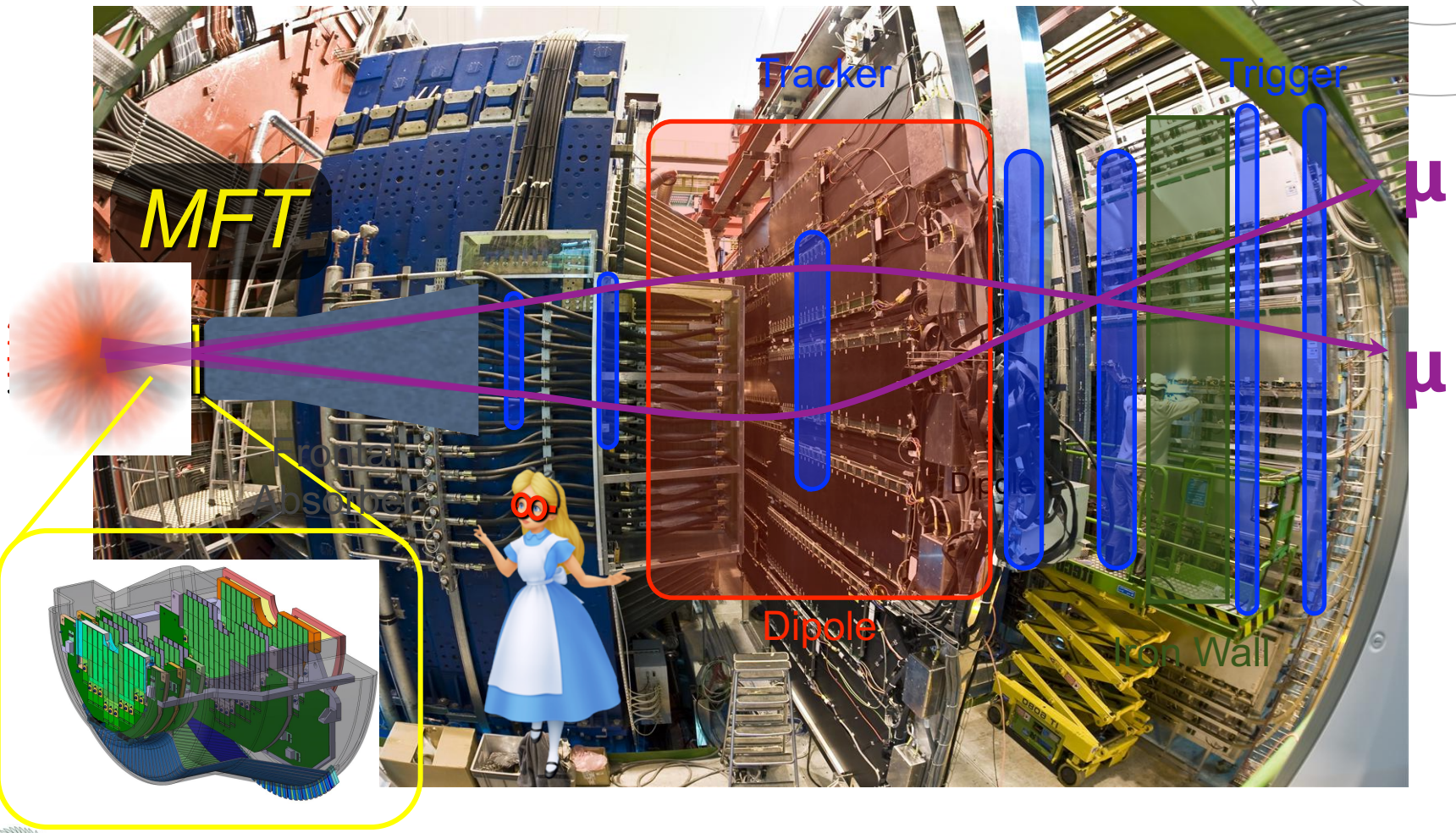
- muon arm: $2.5 < |\eta| < 4.0$
- MFT: $2.5 < |\eta| < 3.6$
  - shoulder of central rapidity plateau (similar to PHENIX)
- minimum $p_T \sim 0.5$ GeV/c





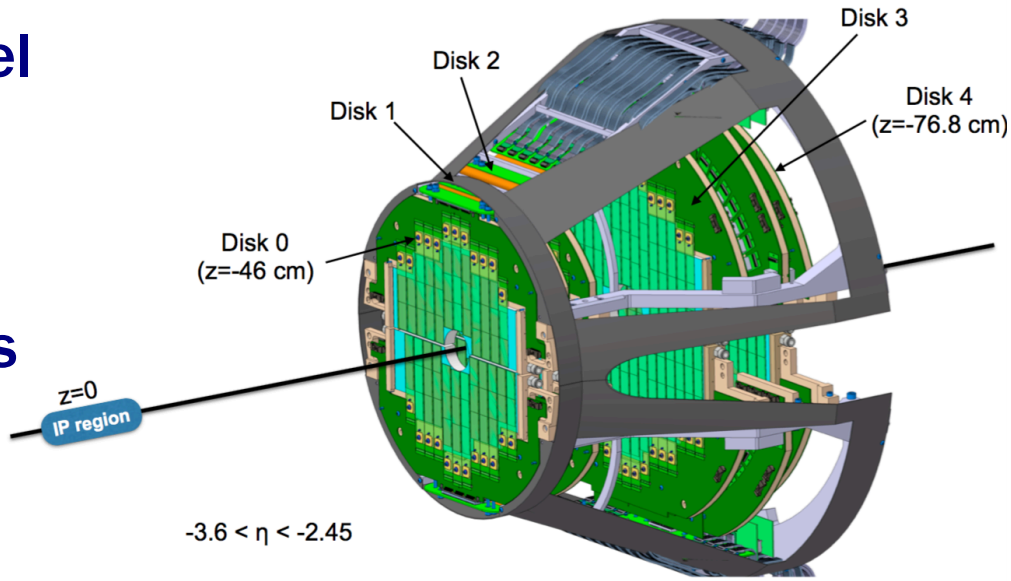
Muon Forward Tracker (2021–)

- vertex and invariant mass resolutions to improve



Muon Forward Tracker Design

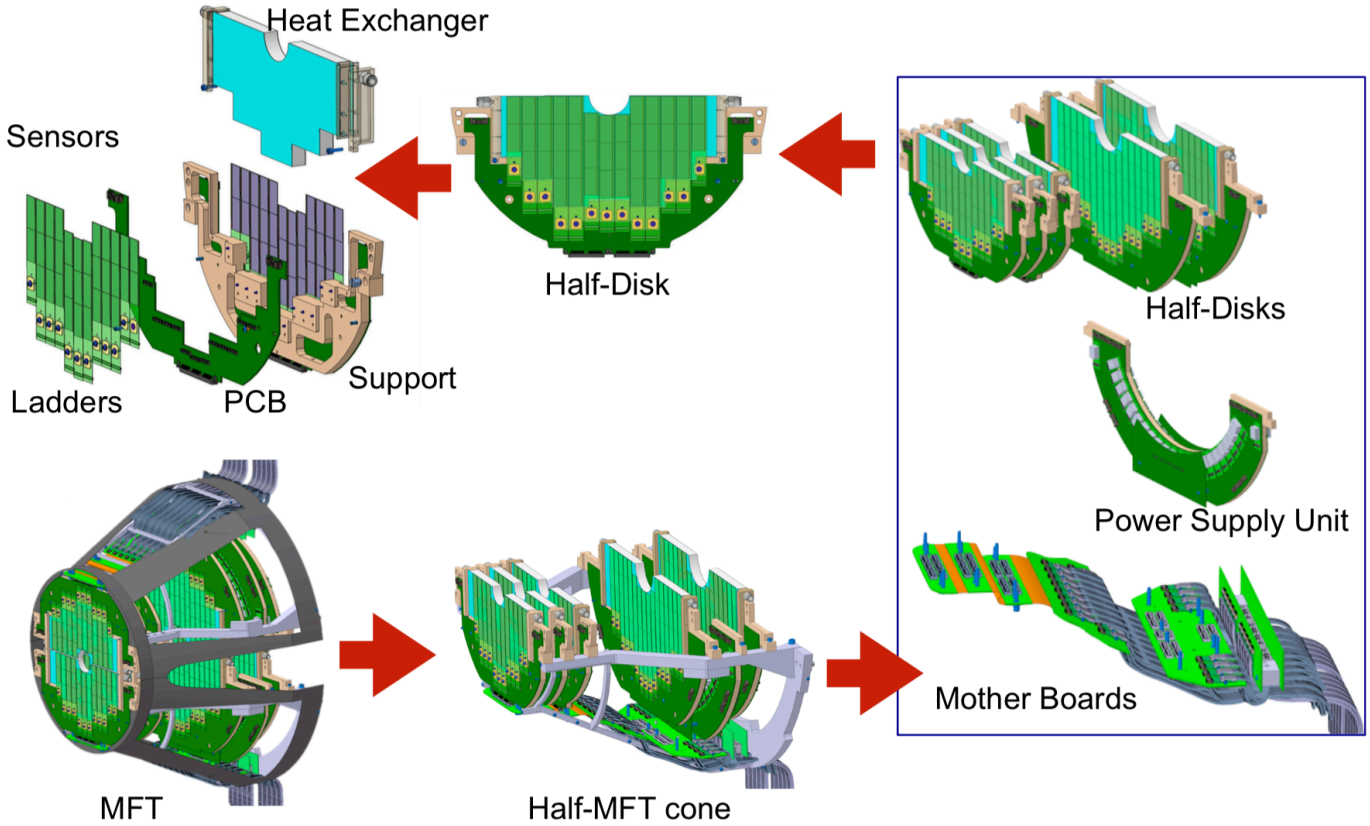
- $2.45 < -\eta < 3.6$
  - $-z = 460-768$ mm
- 0.4 m^2 of MAPS silicon pixel sensors
  - 28 μm × 28 μm pixel
  - 0.35% X_0 per layer
- 10 sensitive layers
  - 5 double sided disks



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

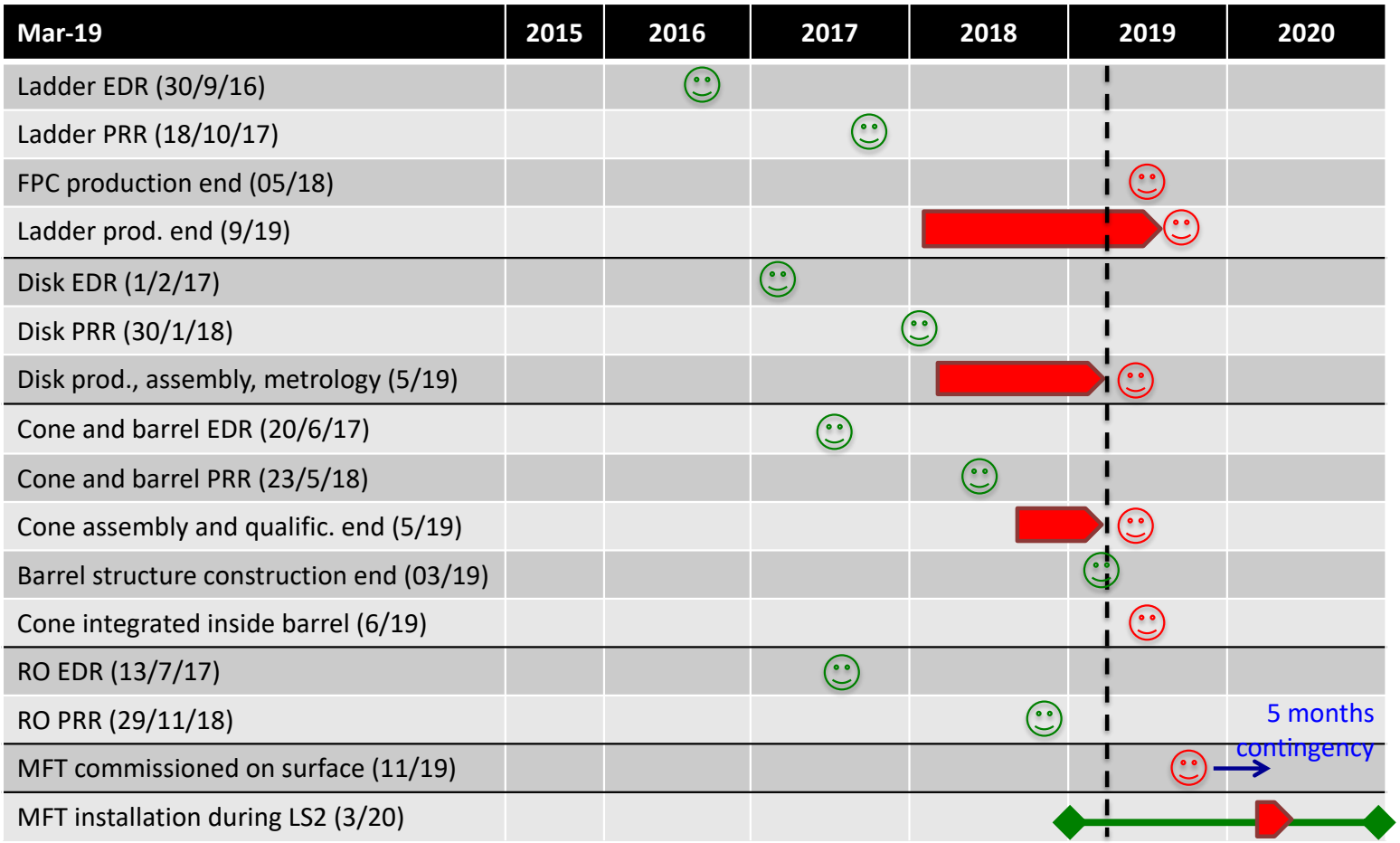
MFT Structure and Elements

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



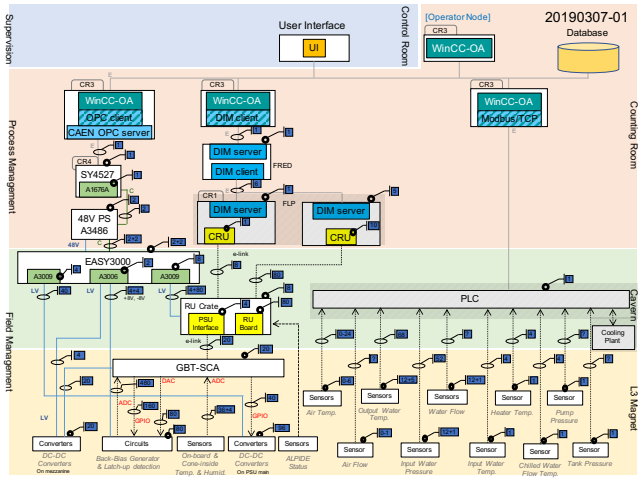
Muon Forward Tracker Milestones

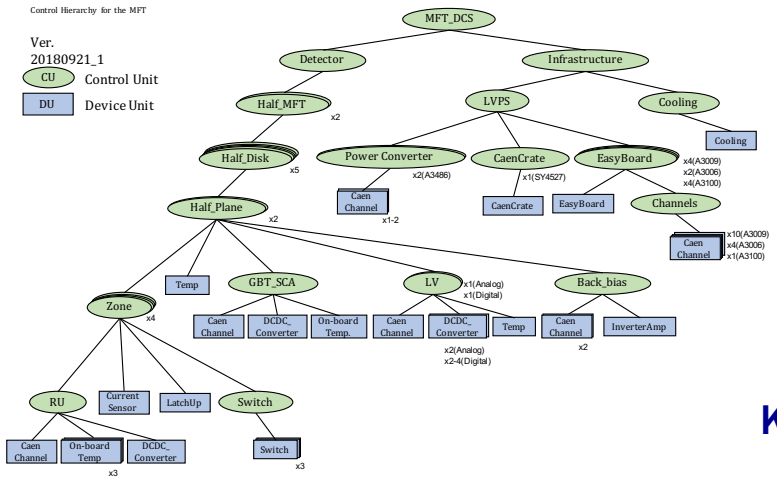
- tight but staying on track in this crucial stage

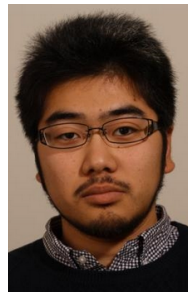


Muon Forward Tracker Control System

- hardware control, finite state machine, interlock
- new architectures in ALICE run 3
  - *e.g.* gigabit transfer slow control adapter (GBT-SCA)
- MFT (Hiroshima/CERN) leading ALICE development



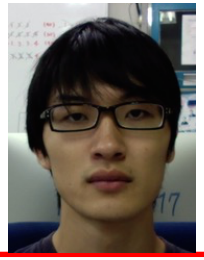




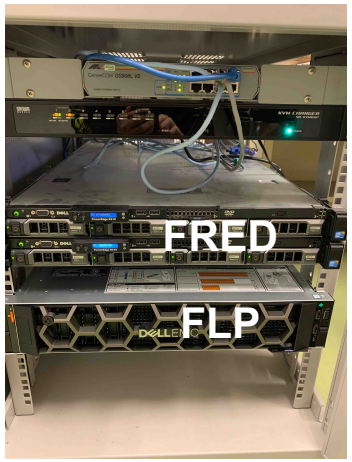
Kosei Yamakawa

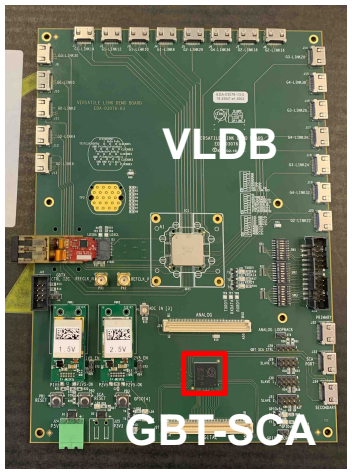
Full Scale DCS Test Bench at Hiroshima

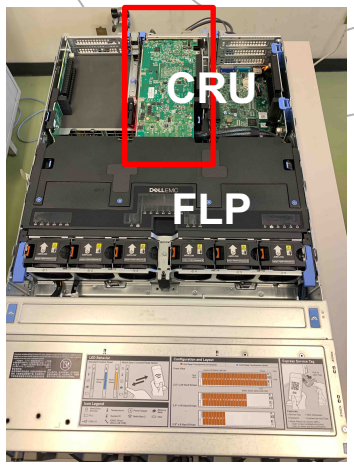
Yorito Yamaguchi

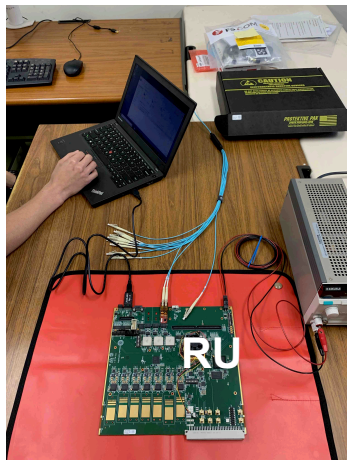


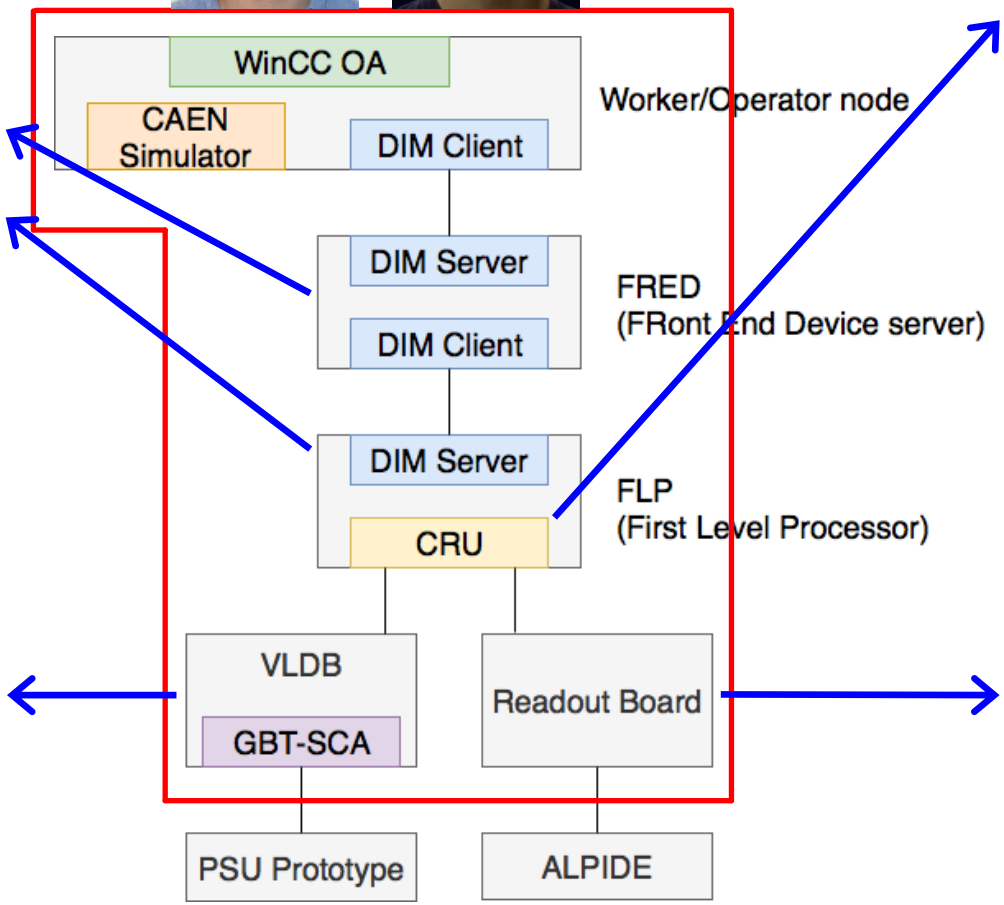
Motomi Oya





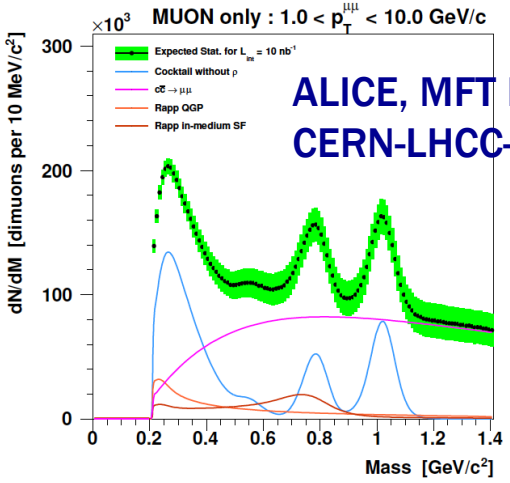




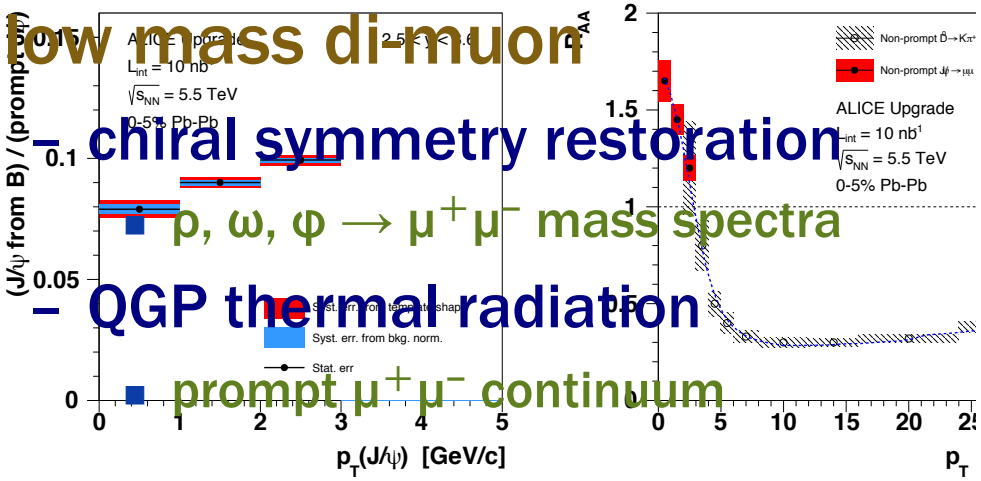


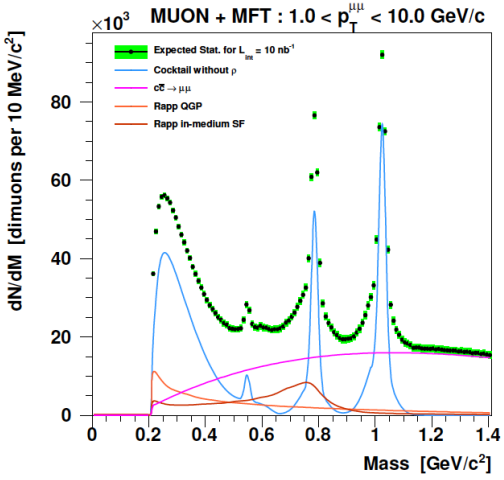
MFT Physics Goals at a Glance

- 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





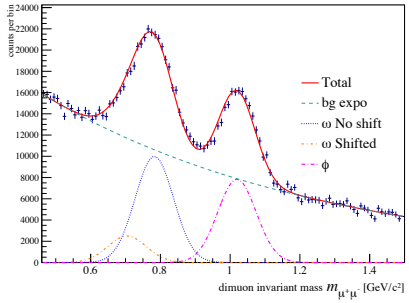
広島大学

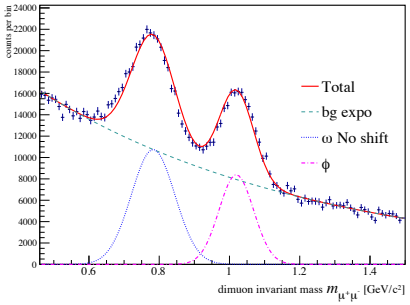
ALICE

Mass Modification Detectability

- evaluation in progress
  - based on simple 2 peak model
    - similar to KEK E325 analysis and J-PARC E16 simulation

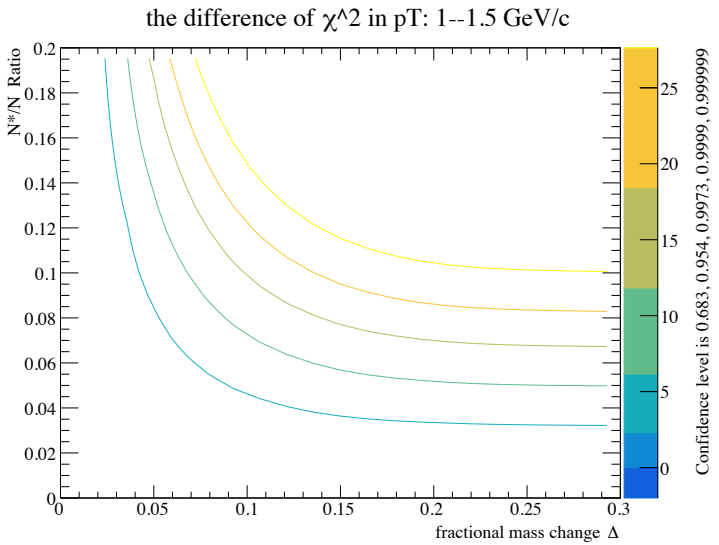
Takehito Kondo





fitting same spectra (containg modification) with and without modified ω component

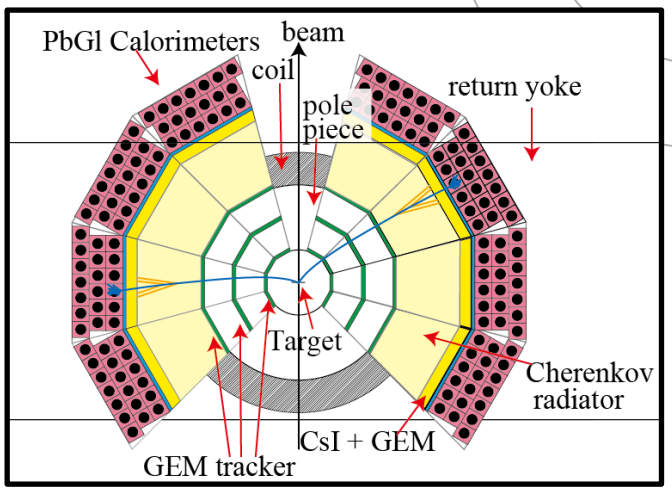
ω in *p*+*p* at √*s* = 7 TeV
ALICE run 2 statistics
1.0 < p_T < 1.5 GeV/c

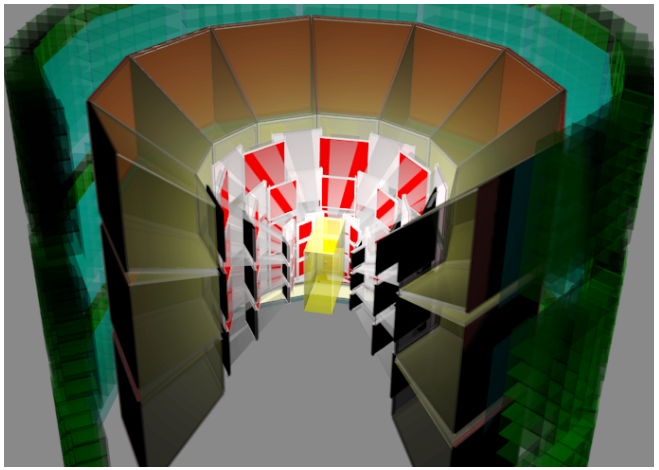


- *p*+A and A+A to be attacked soon

J-PARC E16

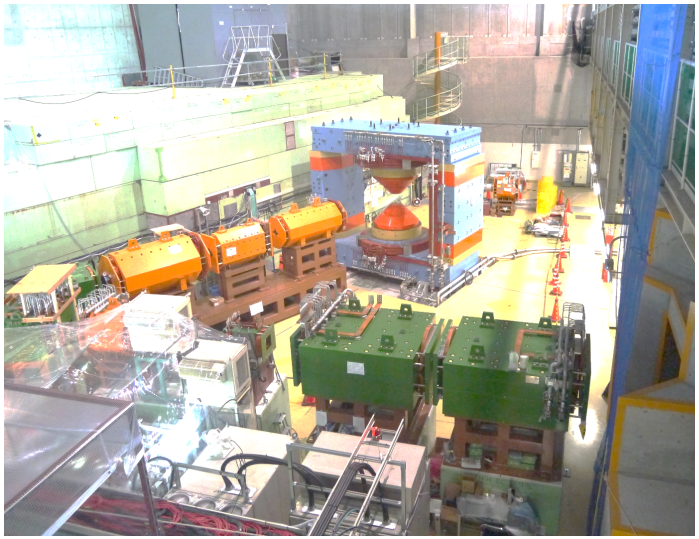
- successor of KEK E325
  - p+A → ρ/ω/φ → e^+e^-
  - not just statistics,
    but more systematics
- pilot run in early 2020
  - 8 partial modules
- run 1 in early 2021 (?)
  - 8 complete modules
  - plan to collect 15 k φ's
- run 2 in 2022 (?)
  - all 26 modules





E16 Finally to Materialize

- BNL, Hiroshima, JAEA, JASRI, KEK, Kyoto, NIAS, Osaka, RIKEN, Tohoku, Tokyo, Tsukuba
- graduate student joining from Hiroshima



Takehito Kondo

Summary and Concluding Remarks

- dileptons to probe rich physics
  - famous penetrating probe of early stage
  - though technically challenging, even more than expected
- low mass low p_T physics yet to be attacked
  - chiral symmetry restoration
  - thermal radiation from initial stage
- new opportunity in dimuons at LHC (and above)
  - along with beloved dielectrons
- ALICE run 3 (2021–) !
- J-PARC E16 in another (density) direction