ALICE Run 3 以降 の μ 粒子測定 による 物理

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「高度化後の ALICE 実験での物理の可能性」研究会
長崎総合科学大学
2018 年 8 月 17 日

Presentation Outline

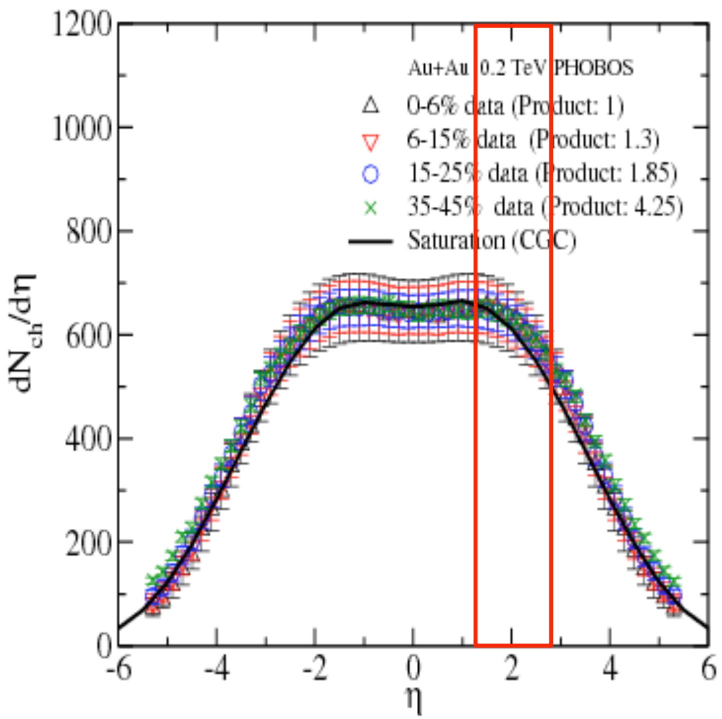
- electron and muon reunion at LHC
- ALICE muon measurement major upgrade
  - Muon Forward Tracker
- physics shopping list and approaches via muons
  - mechanism and prerequisites of phase transition
  - quark behavior in strong QCD field
  - quarks interaction in strong QCD field
  - chiral symmetry restoration
  - more exotics
- summary and concluding remarks

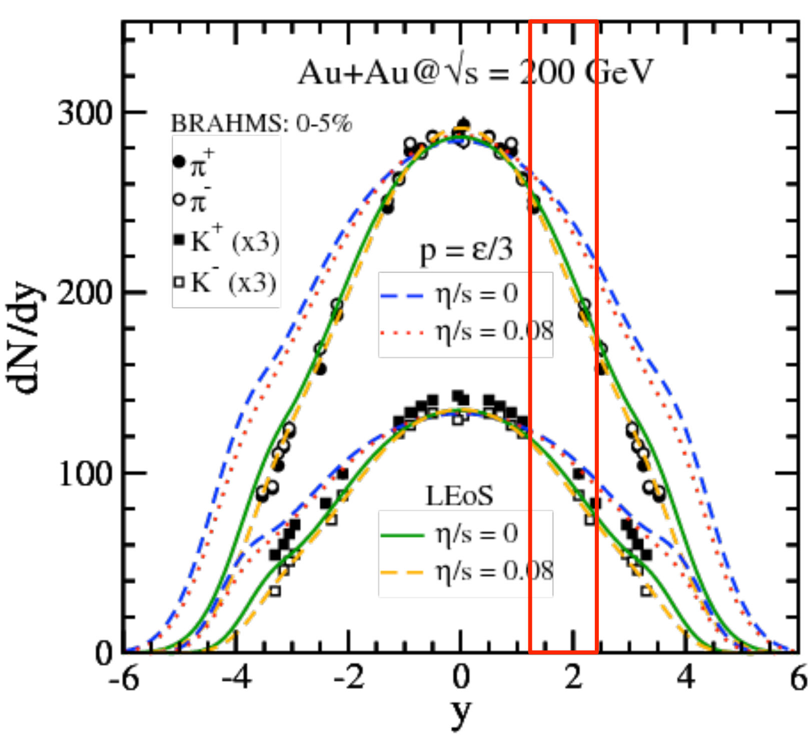
e and μ Reunion at LHC Energy

- parallel approaches to same physics up to SPS
  - muons at central (CMS) rapidity in fixed target exp.
    - *e.g.* NA38/50/51/60 dimuon spectrometer
- physics emphasis (and people) separated at RHIC
  - broad QGP physics with electrons in central barrel
  - focused topics, *e.g.* high mass/p_T and spin, with muons
    - *e.g.* PHENIX “forward” arms
    - low momentum μ ID technically challenging
- reunion at LHC
  - low p_T muons within prolonged central Bjorken plateau
  - parallel and complementary approaches (again)

Muon Measurement at PHENIX

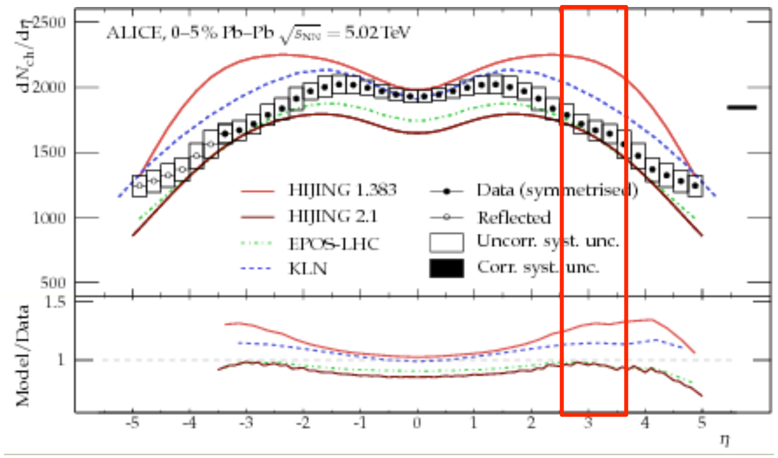
- muon arms: $1.2 < |\eta| < 2.4$
- minimum p_T ~ 1.0 - 1.5 GeV/c

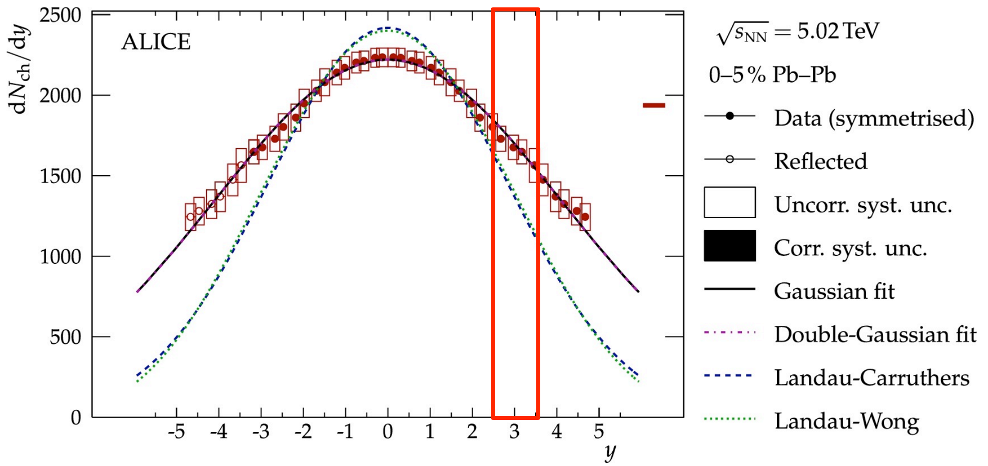




Muon Measurement at ALICE

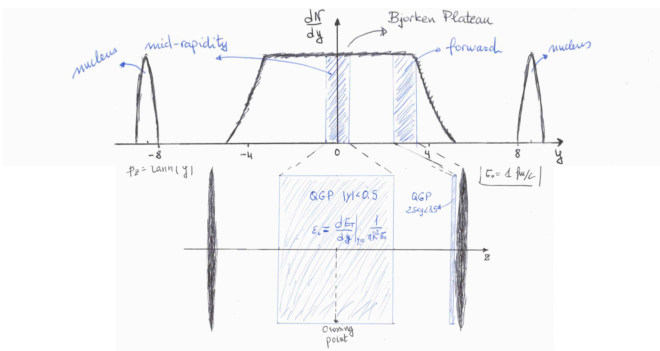
- muon arm: $2.5 < |\eta| < 4.0$
- MFT: $2.5 < |\eta| < 3.6$
- minimum p_T ~ 0.5 GeV/c

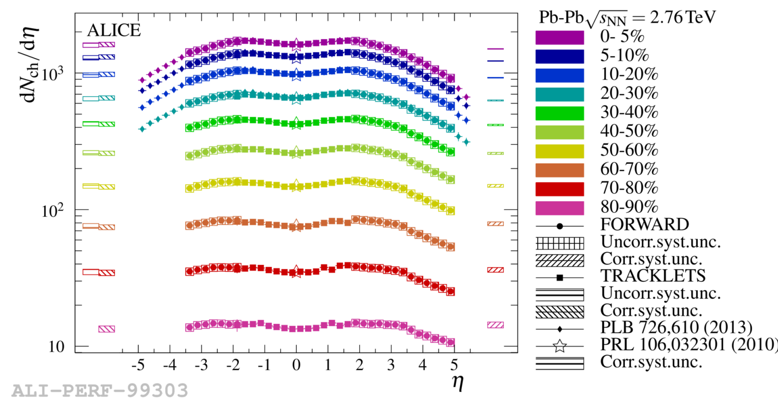




New Relation between e and μ at LHC

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

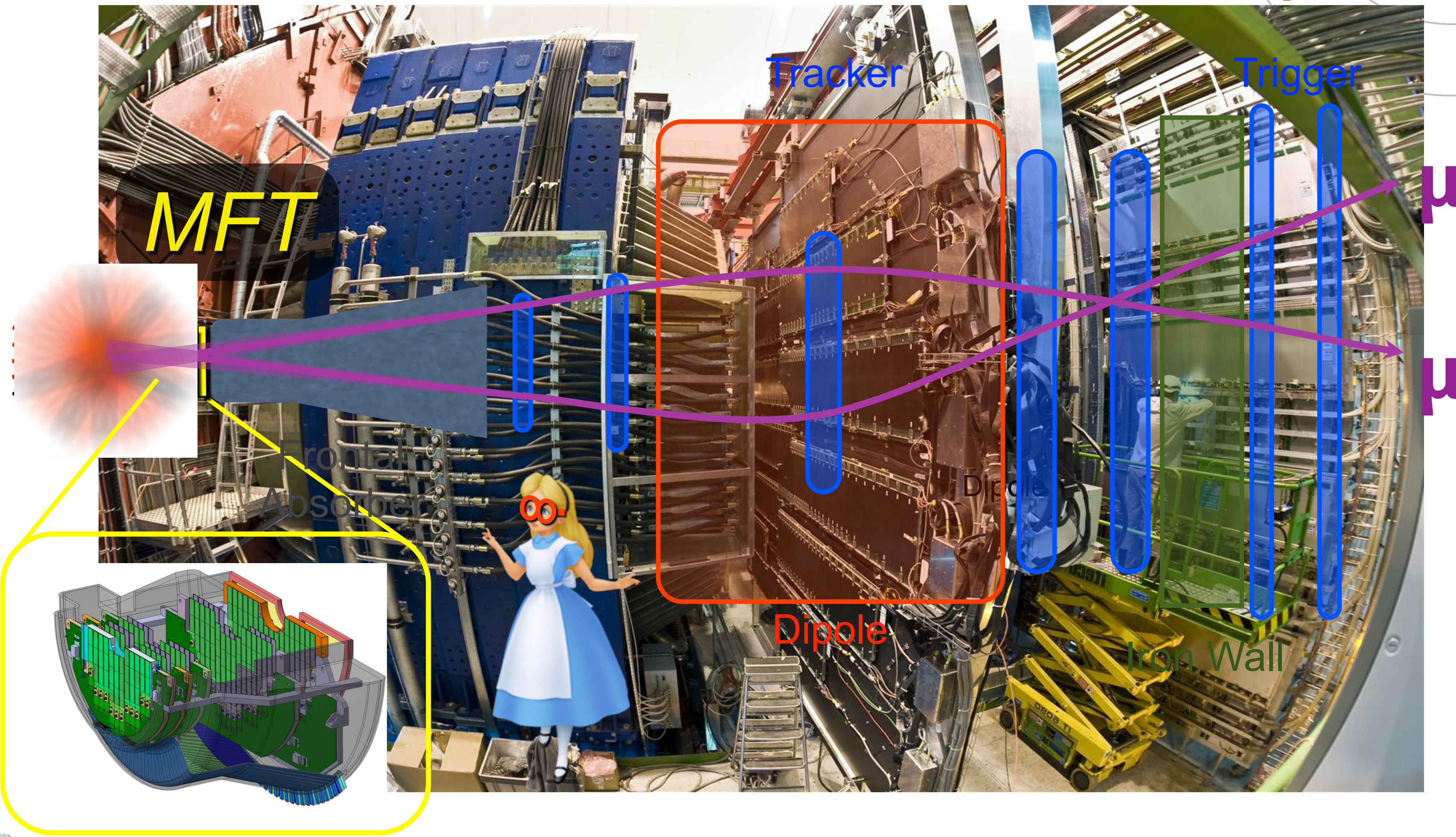




- new opportunity only at LHC energy (and above)
  - ***forward enough*** for (low p_T) muon measurement
    - *e.g.* |y| above ~ 3.4 for p_T < 0.25 GeV/c, p > 4 GeV/c
  - ***not too forward*** for "central" physics
    - |y| up to ~ 4 at LHC (~ 2 at RHIC)

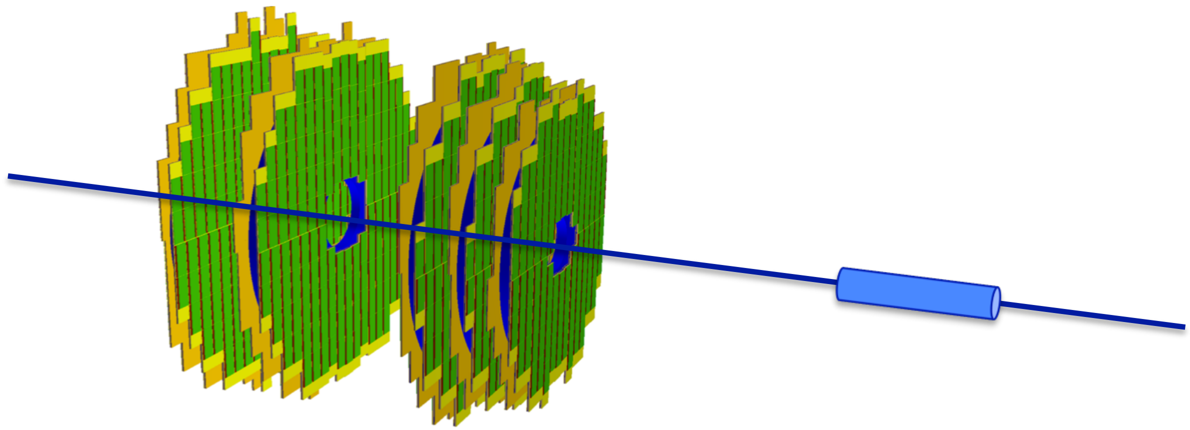
Muon Forward Tracker (2021–)

- vertex and invariant mass resolutions to improve



Muon Forward Tracker Design

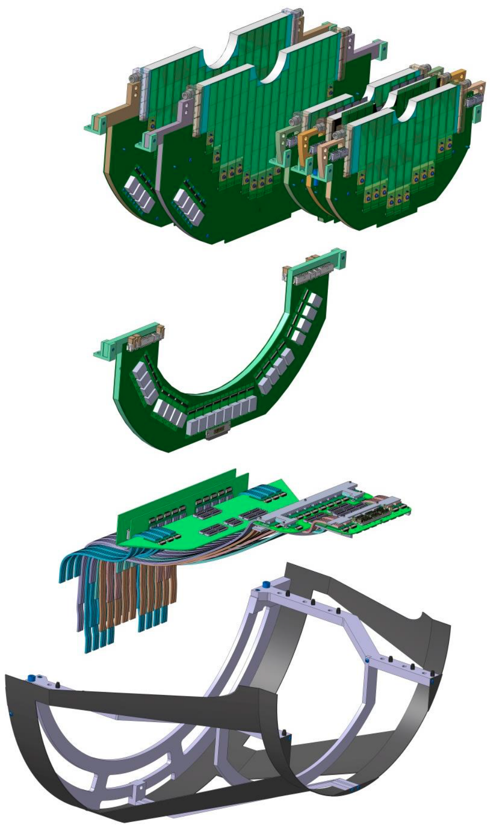
- $2.45 < -\eta < 3.6$
- 0.4 m^2 of MAPS silicon pixel sensors
  - 25 μm x 25 μm, 0.7% X_0 per disk
- 5 double sided disks at $-z$ = 460–768 mm

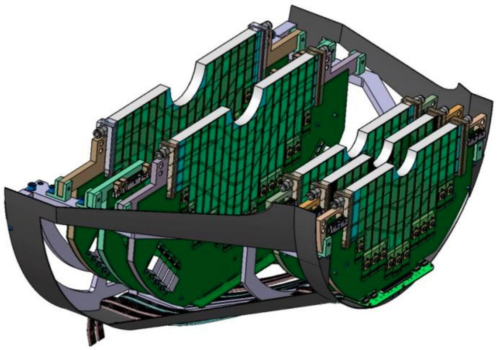


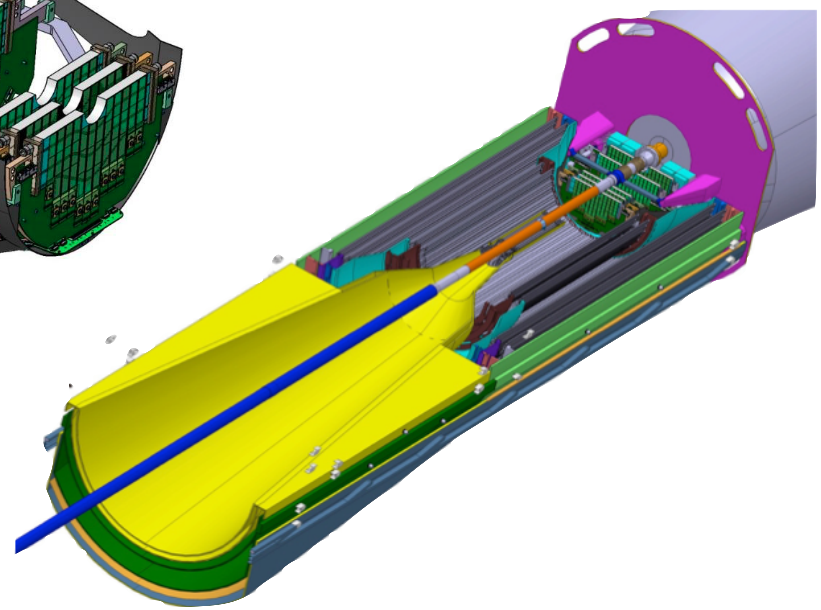
- PbPb ~50 kHz, *pp* ~200 kHz
- matching between MFT and muon spectrometer

MFT Structure and Elements

- chip (920)/ladder (280)/zone (80)/half plane (20) /half disk (10) + PS unit (2)/half MFT (2)/MFT (1)

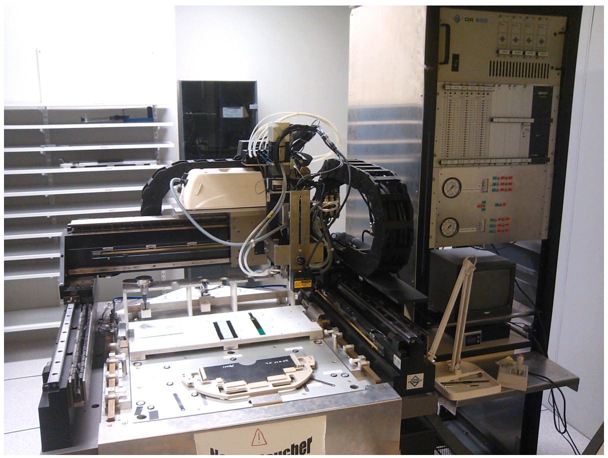


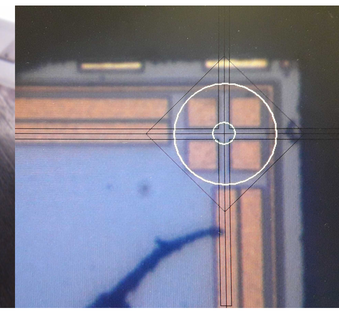
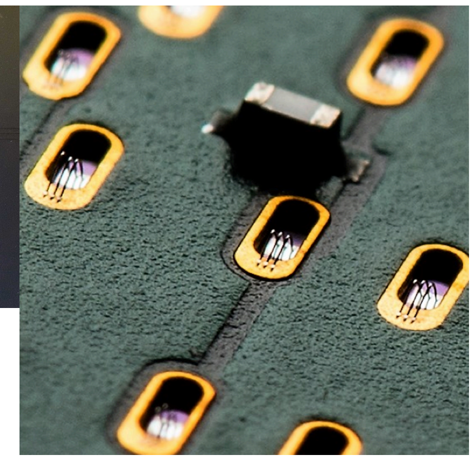
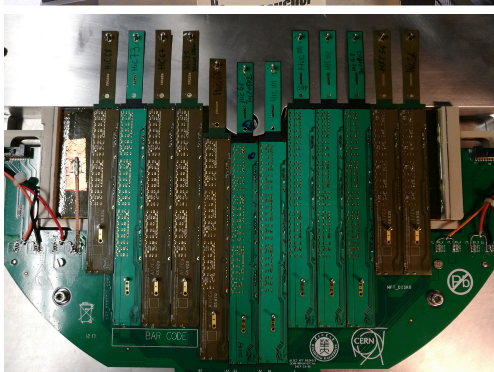
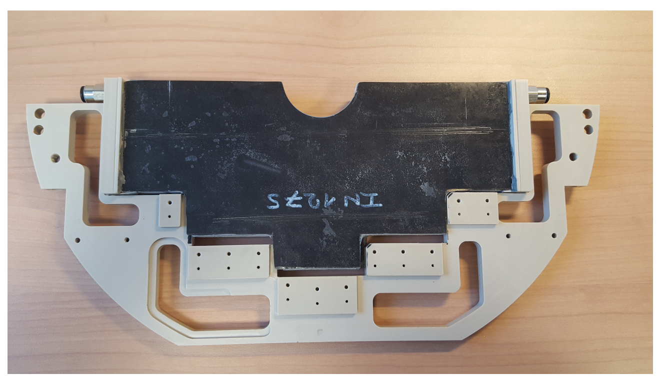
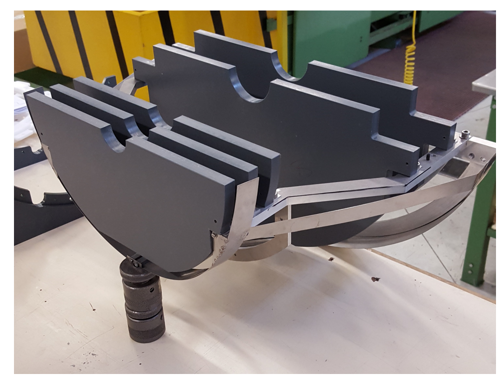




MFT Progresses

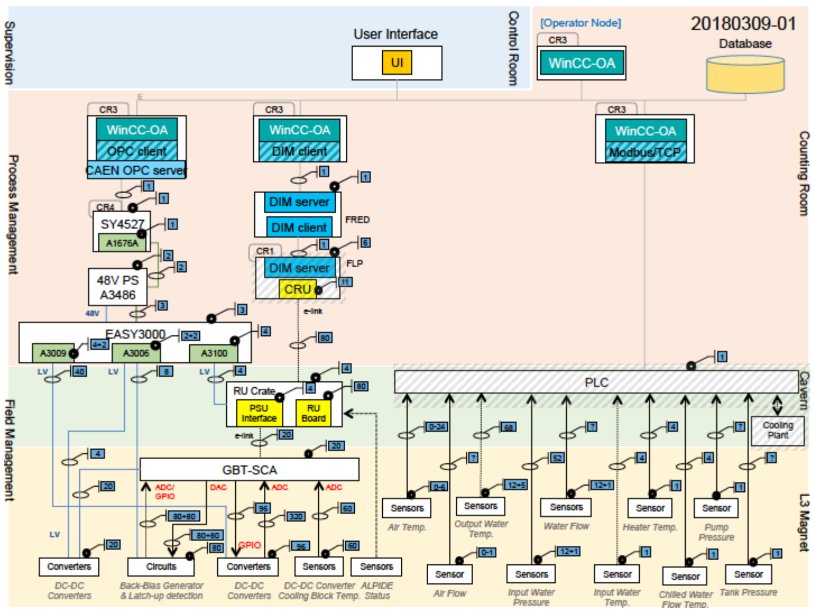
- R&D review mostly passed by 2017
- all components prototyped; production started

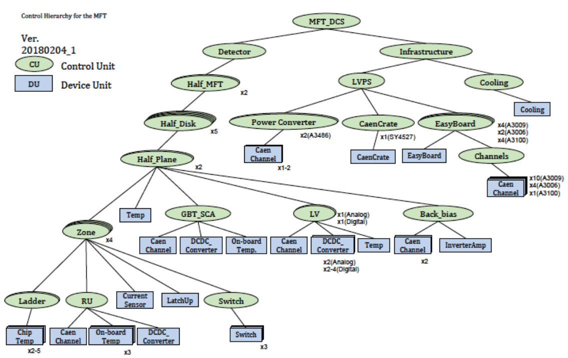


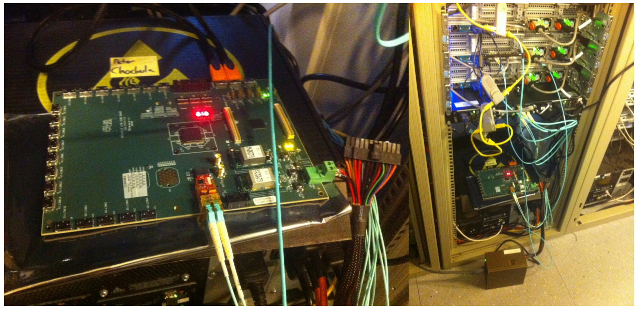






MFT Control System by Hiroshima

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

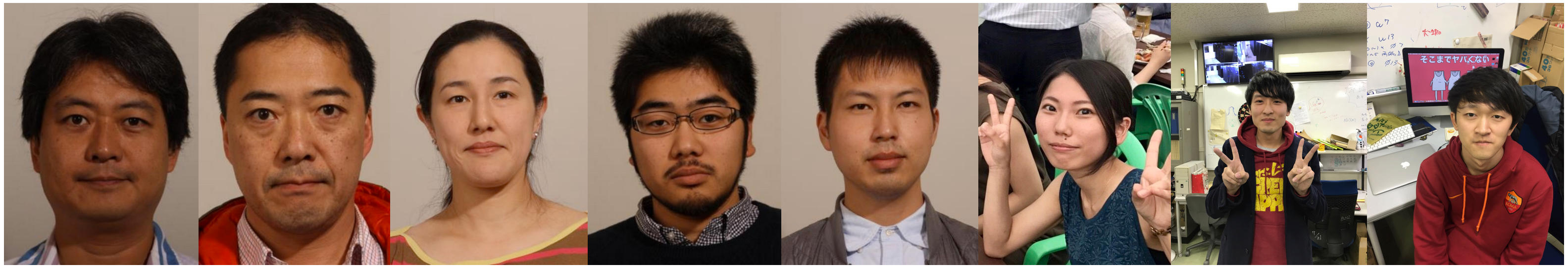






MFT Japan

- Hiroshima U, Nara WU, Nagasaki IAS
- various key contributions
  - control system responsibility
  - ladder production and QA at CERN
  - physics, especially in low mass and exotics



Collaboration with MFT France

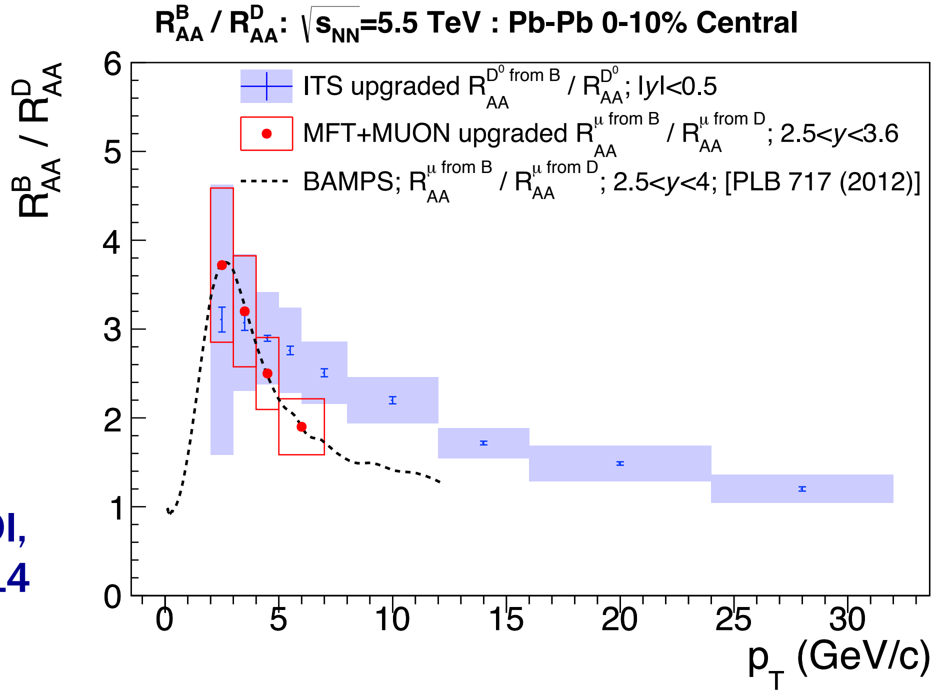
- Subatech, IPN Lyon, LP Clermont, Irfu Saclay
- leading roles
  - sensor, ladder, disks, cone, barrel, read-out, LV, physics
- existing muon tracking and trigger detectors
  - construction, operation, maintenance, analysis, upgrade
- joint post-doc and PhD students supervision

Physics Attacked/Attacking/To Attack

- deconfined quark/gluon phase now in hand
- quark behavior in strong QCD field
  - energy loss and redistribution
- quarks interaction in strong QCD field
  - color Debye screening to melt quarkonia
- chiral symmetry restoration
  - hadron mass modification
- more exotics
  - physics under ultra-intense magnetic field and vorticity

Open Heavy Flavor

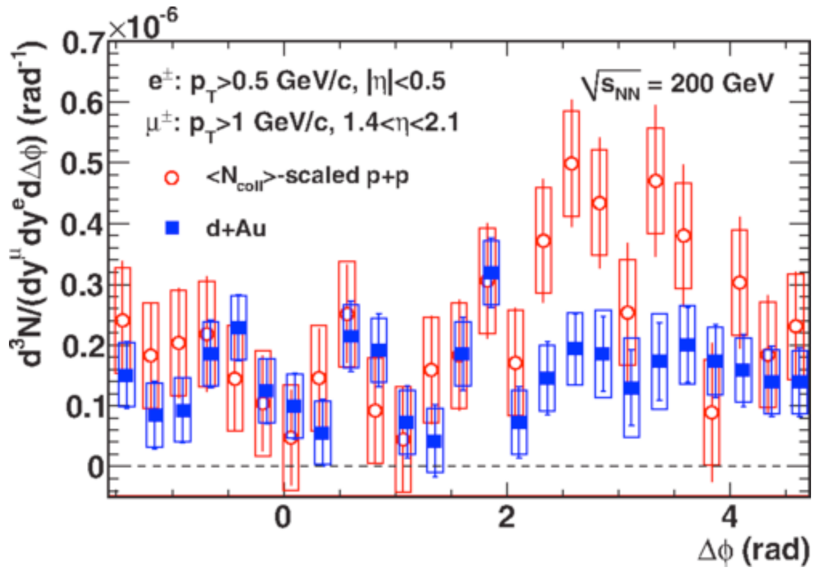
- **current interest: difference bet. charm and beauty**
  - *note:* K. Nagashima (Hiroshima) working on electrons in PHENIX
- **MFT to provide:**
  - **charm/beauty meson separation down to p_T = 0 GeV/c**



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

e - μ Correlation

- $c\bar{c}/b\bar{b} \rightarrow D\bar{D}/B\bar{B} \rightarrow X\ e\ Y\ \mu$
- long awaited golden channel for open heavy flavor
  - little physics background
- PHENIX data in *pp*, *d*Au



PHENIX, PRC 89, 034915 (2014)

- independent triggers till ALICE run 2
- no triggering for PbPb from ALICE run 3

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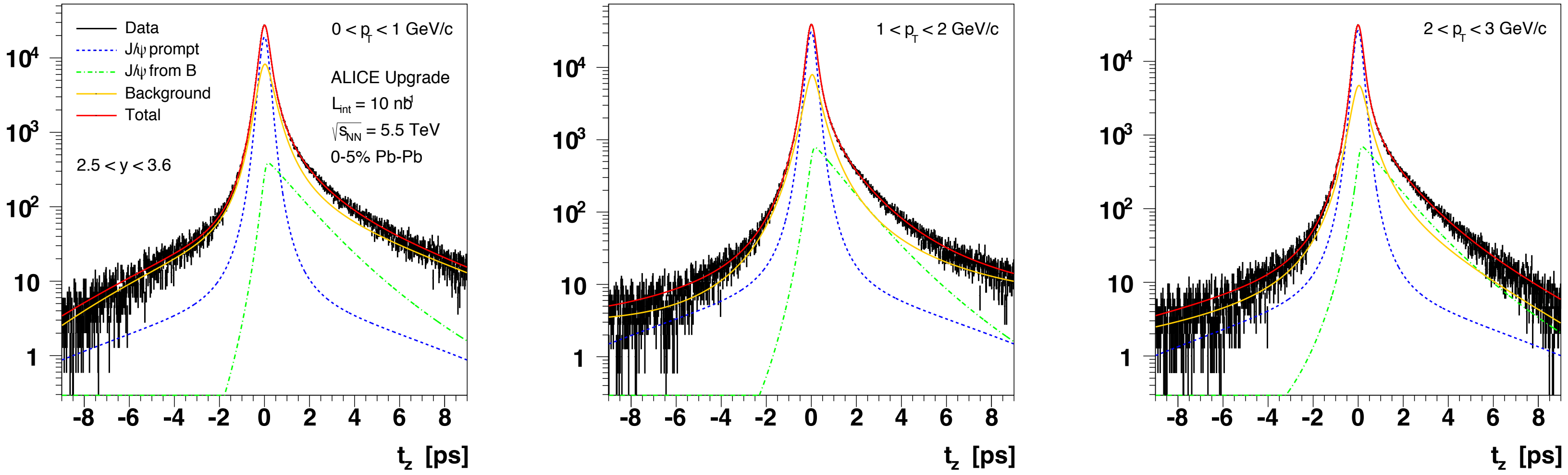
Quarkonia

- current interest: sequential melting thermometer
- MFT to provide:
  - J/ψ down to p_T = 1 GeV/c
  - feed down (*e.g.* B → ψ + X) identification



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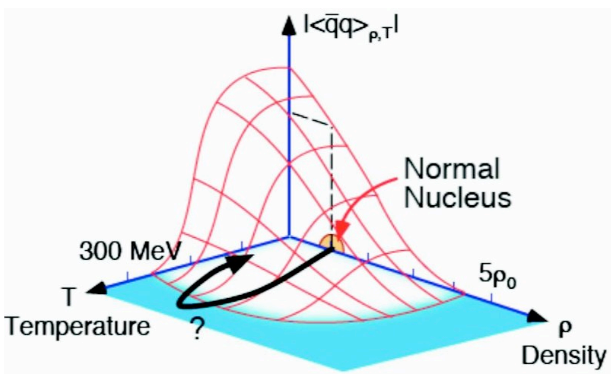
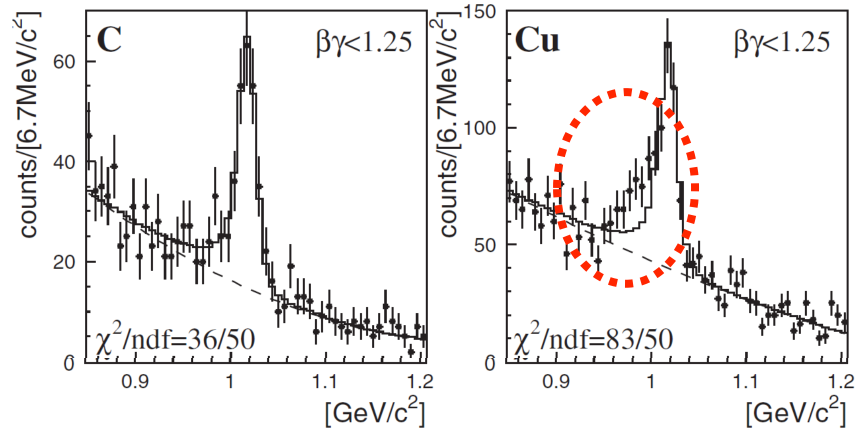
Chiral Symmetry Restoration

- “observations” 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)

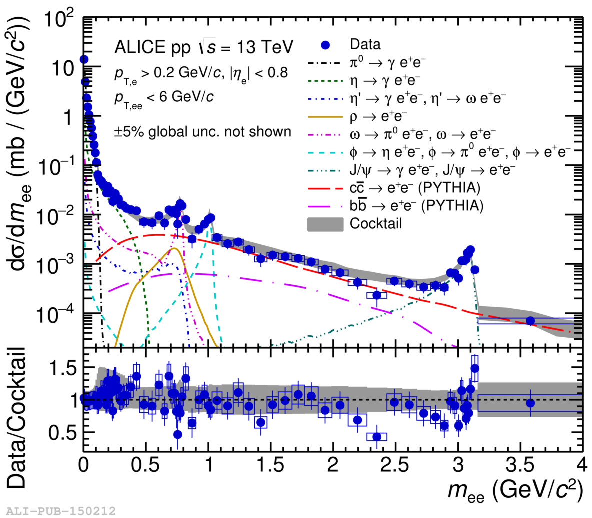


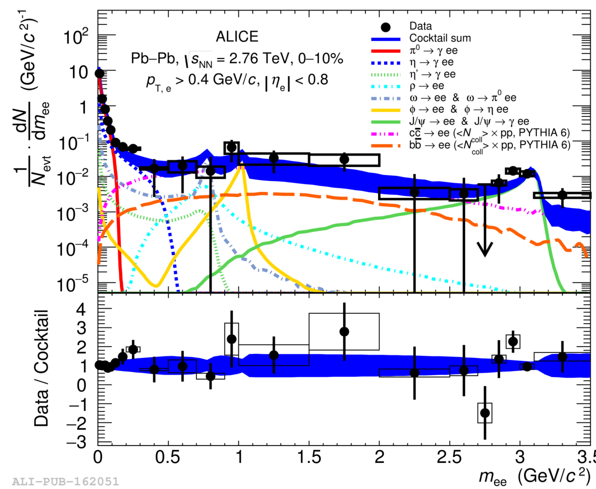


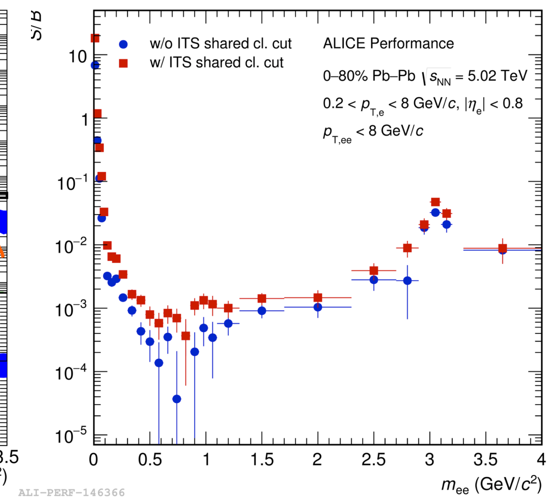
- no evidence in high temperature regime yet
  - challenging dilepton measurements
    - *e.g.* PHENIX with RICH, hadron blind detector, ...

Dielectrons at ALICE

- first results published from runs 1, 2
  - *pp* 7 TeV, 13 TeV, central PbPb 2.76 TeV
  - very challenging S/B ratio in PbPb







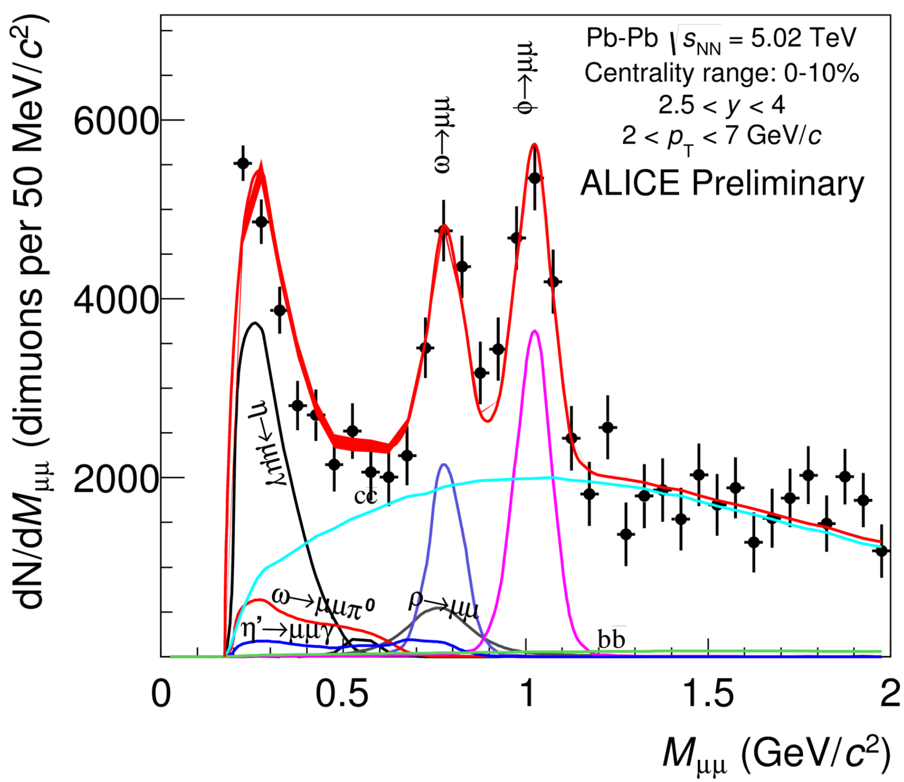
ALICE,
arXiv:1805.04407 [hep-ex]
submitted to Phys. Lett. B

ALICE,
arXiv:1807.00923 [hep-ex]
submitted to Phys. Rev. C

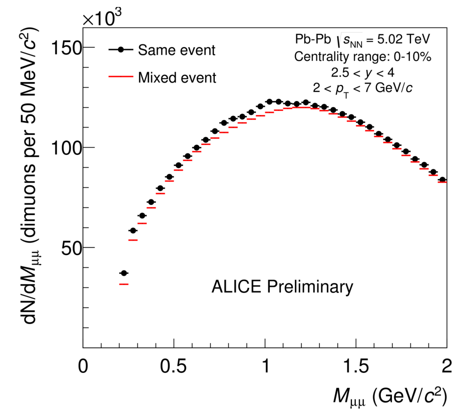
- see TPC related presentations at this workshop

Low Mass Dimuons at ALICE

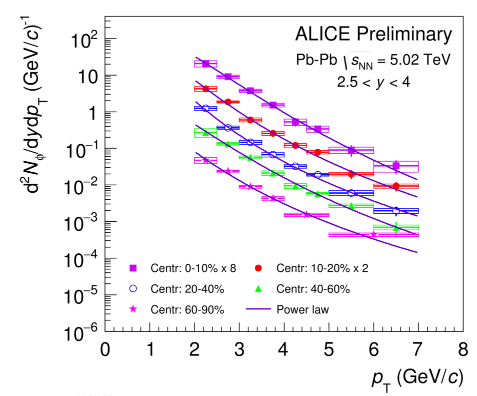
- very clean low mass (ϕ, ω, ρ) $\mu^+\mu^-$ measurement
  - even further improvement with upgrades from run 3



ALI-PREL-121162



ALI-PREL-121195

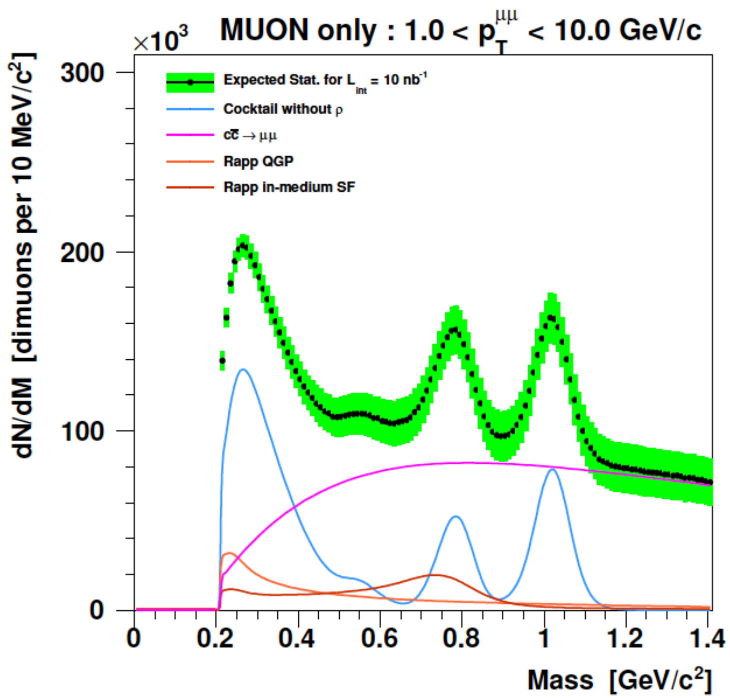


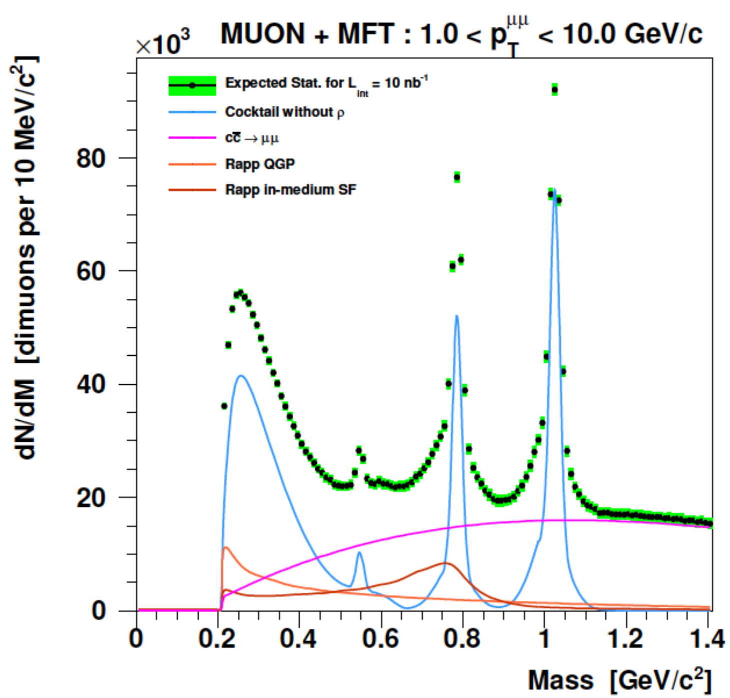
ALI-PREL-117465

Low Mass Dimuons with MFT

- significant improvement
  - mass resolution by ~4
  - signal/background ratio by ~10
  - detailed feasibility study in progress

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





Physics Attacked/Attacking/To Attack

- deconfined quark/gluon phase now in hand
  - mechanism and prerequisites of phase transition
- quark behavior in strong QCD field
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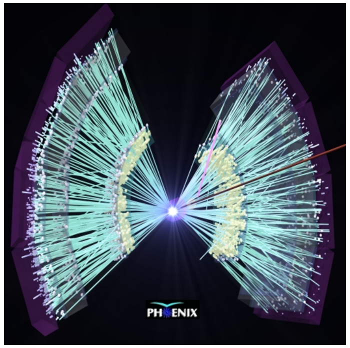
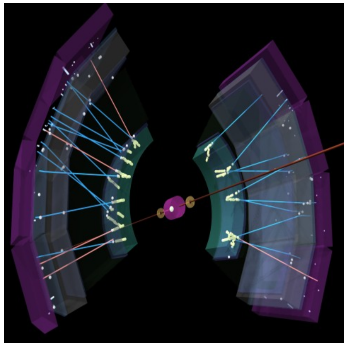
  - physics under ultra-intense magnetic field and vorticity

Something Unknown in *p*(*d*)A

AuAu at $\sqrt{s_{NN}}$ = 200 GeV





*d*Au at $\sqrt{s_{NN}}$ = 200 GeV

- original thought: cold nuclear matter, *i.e.*
  - *not* partonic
  - *not* dense
  - *not* strongly coupled
  - *not* hot
- indications of strongly coupled partonic matter??
  - see T. Hirano's presentation at this workshop
  - *note:* only in high multiplicity events; still valid reference

Next Steps with High Multiplicity *pp*, *pA*

- partonic hydro-dynamical behaviors already seen
  - mass dependent spectrum hardening
  - baryon enhancement (“anomaly”)
- medium properties, *e.g.* strange chemical potential
  - (multi-)strangeness enhancement
- parton energy loss probably hard to observe
  - path length ~ medium size
- thermal radiation?
- quarkonia suppression?
- high luminosity high statistic data essential
  - < 1% high multiplicity event selection

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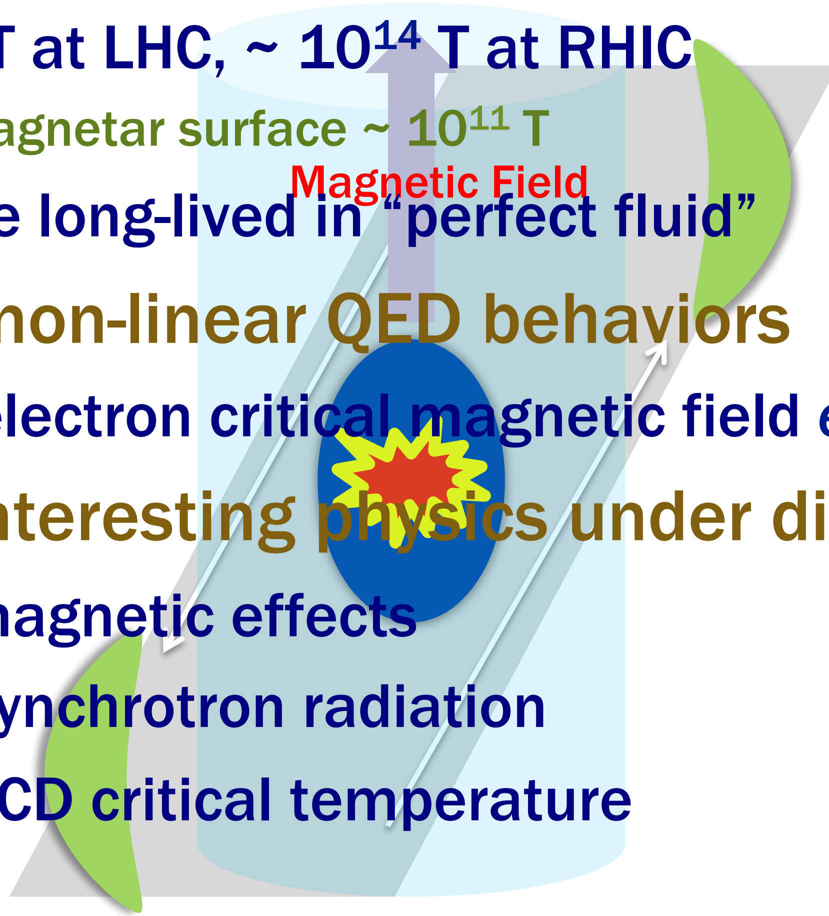
Ultra-Intense Magnetic Field

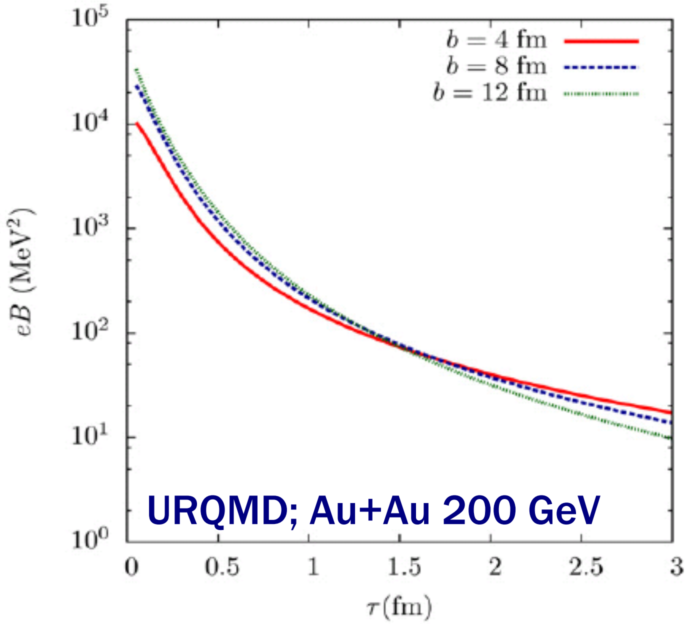
- U(1) magnetic field
  - naturally expected with moving charged sources (nuclei)
  - ~ 10^{15} T at LHC, ~ 10^{14} T at RHIC
    - *cf.* magnetar surface ~ 10^{11} T
  - could be long-lived in “perfect fluid”

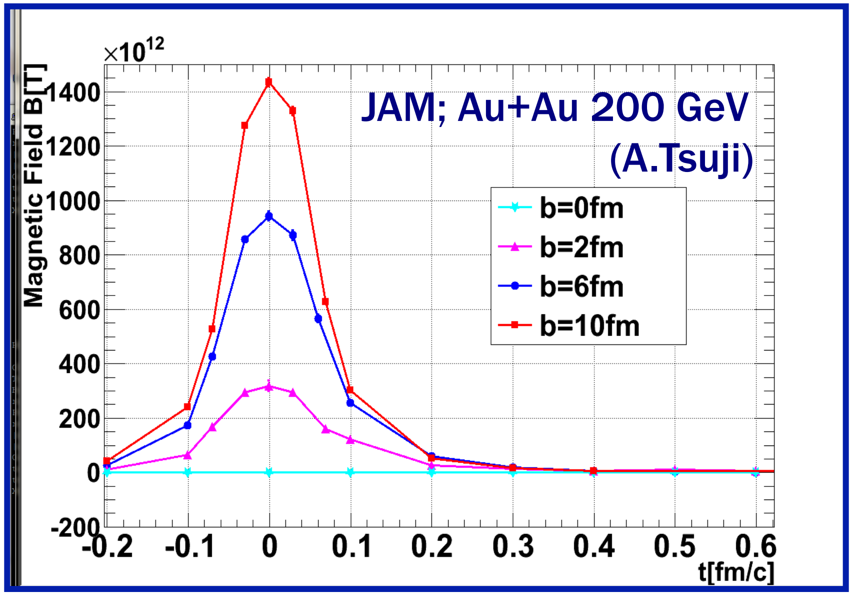


- possible non-linear QED behaviors
  - above electron critical magnetic field $em_e^2 = 4\times10^9$ T
- various interesting physics under discussion
  - chiral magnetic effects
  - quark synchrotron radiation
  - lower QCD critical temperature

Field Intensity and Time Evolution

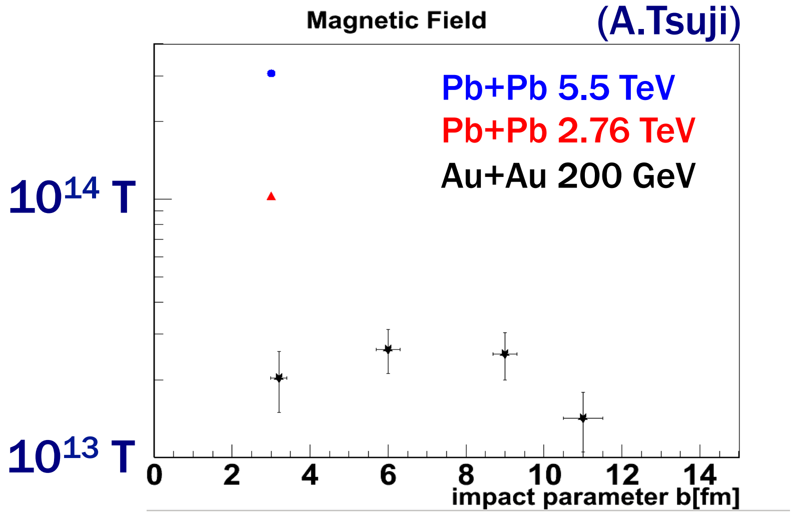
- common approach: cascade models
  - spectator contribution dominant
    - 10^{14} – 10^{15} T at LHC
    - short life time < 1 fm/c due to Lorentz contraction
    - though still above m_e^2/e after several fm/c

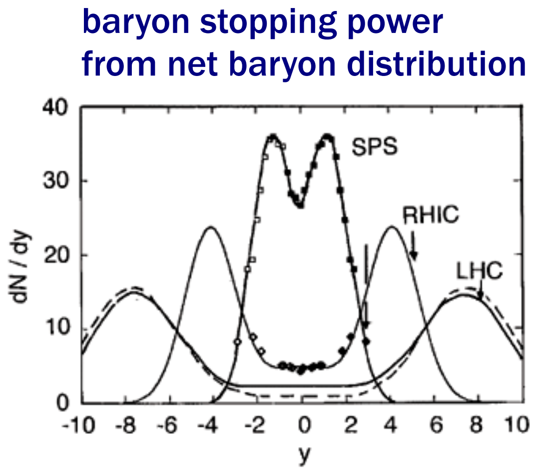




Field Possibly Longer Lived

- long lived participant contribution in perfect fluid?
  - "static field" approximation w/ Glauber model
    - finite baryon stopping taken into account
    - 10^{13} – 10^{14} T at LHC

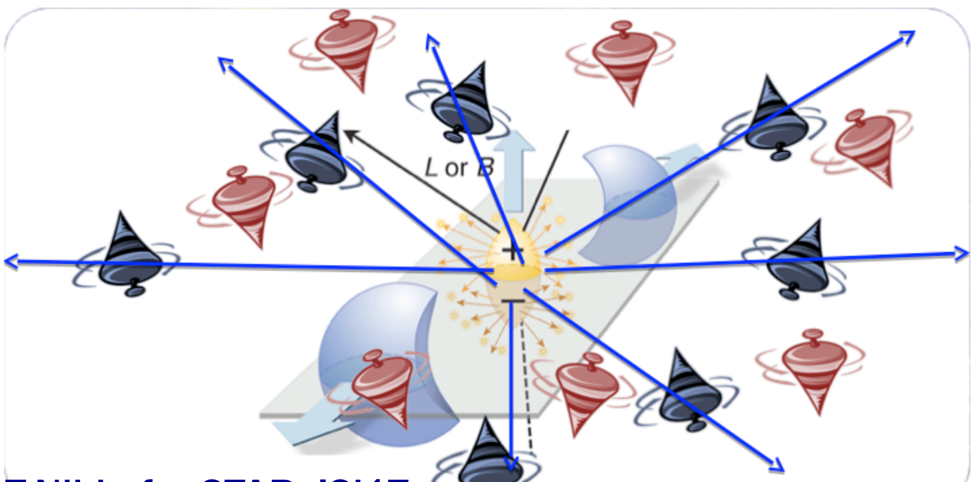




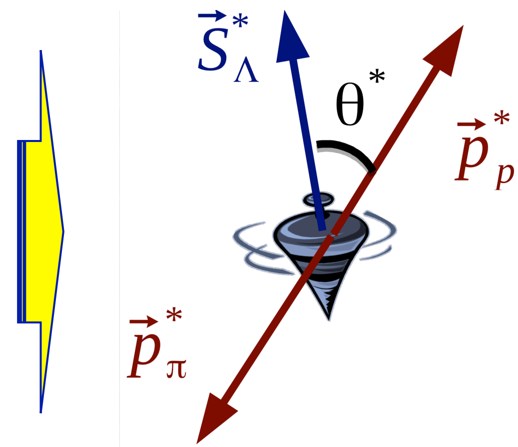
- hydro model with local charge nearly available

Vorticity (and/or Magnetic Field)

- angular momentum transfer to Λ polarization
  - spin - orbit coupling
- magnetic field also possible Λ polarization source
  - opposite alignment of Λ and $\bar{\Lambda}$



T.Niida for STAR, IS'17

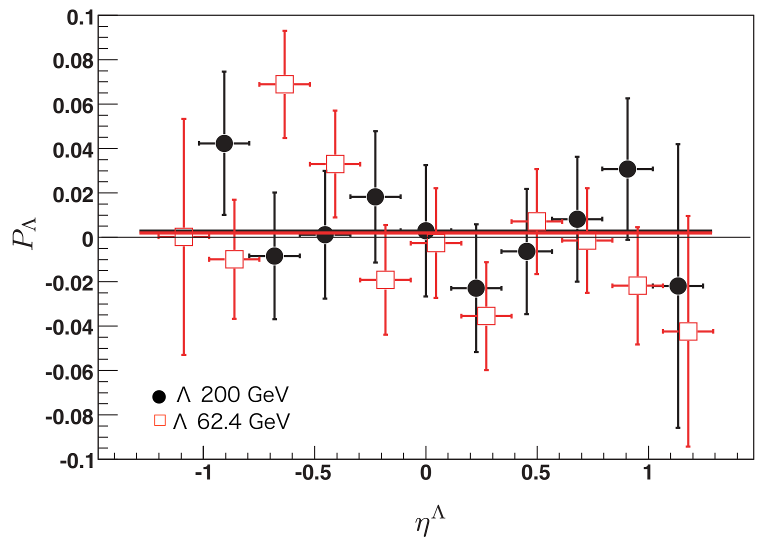


- detectable via parity violating Λ decay

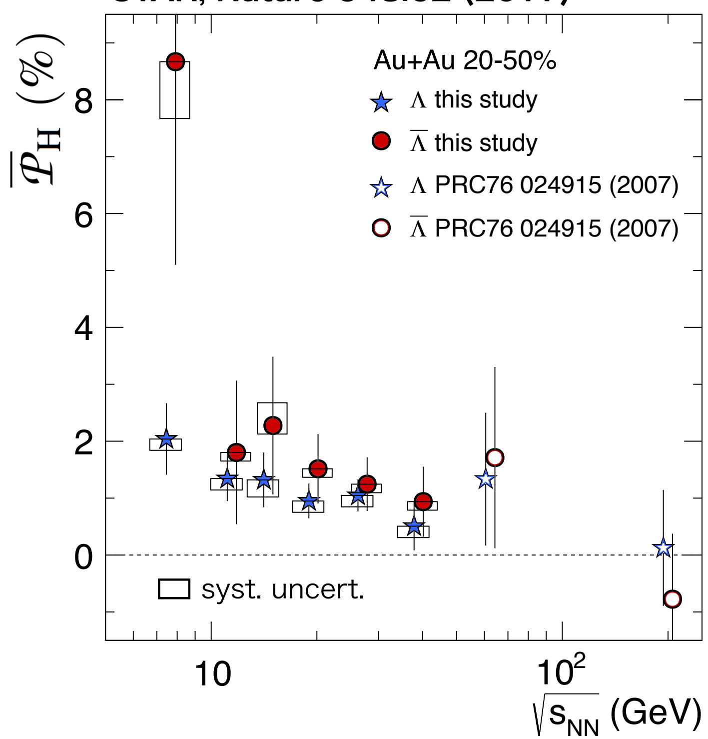
Λ Polarization Measurements

- successful example of precision improvement
  - zero consistent with upper limit at 0.2% in 2007
  - $\sqrt{s_{NN}}$ dependent polarization found by 2017

STAR, PRC76, 024915 (2007)



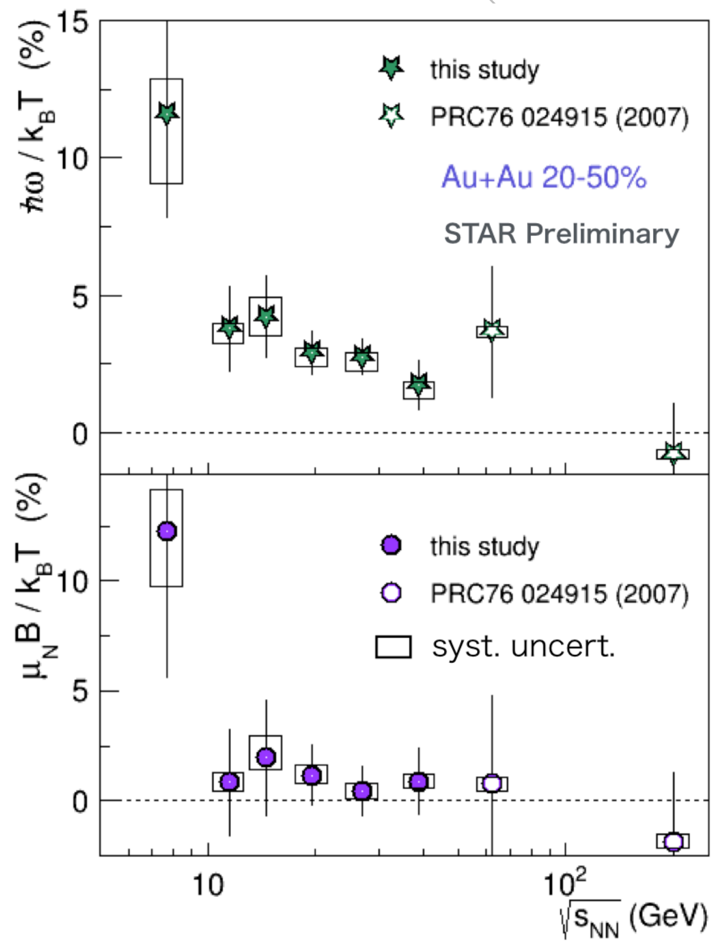
STAR, Nature 548.62 (2017)



広島大学

Non-Zero (and Large) Vorticity Found

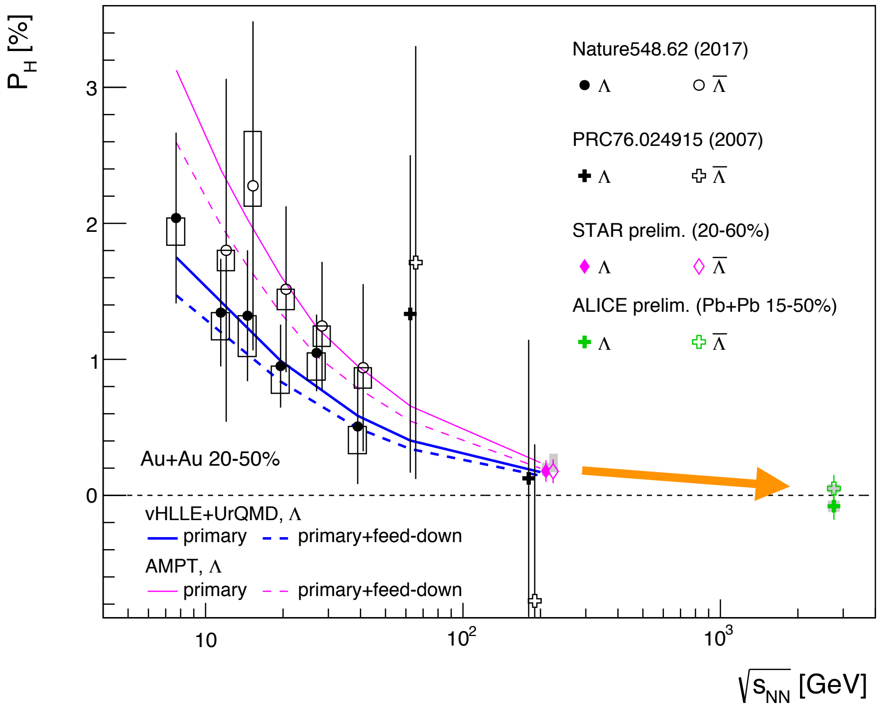
- $\omega = (9 \pm 1) \times 10^{21}\ s^{-1}$
  - $\sqrt{s_{NN}}$ averaged
  - assuming T = 160 MeV
- magnetic field?
  - implied by Λ and $\bar{\Lambda}$ difference
  - though still zero consistent



T.Niida for STAR, IS'17

Implications for Magnetic Field Search

- magnetic field not yet caught
- long-lived medium rotation; very promising source

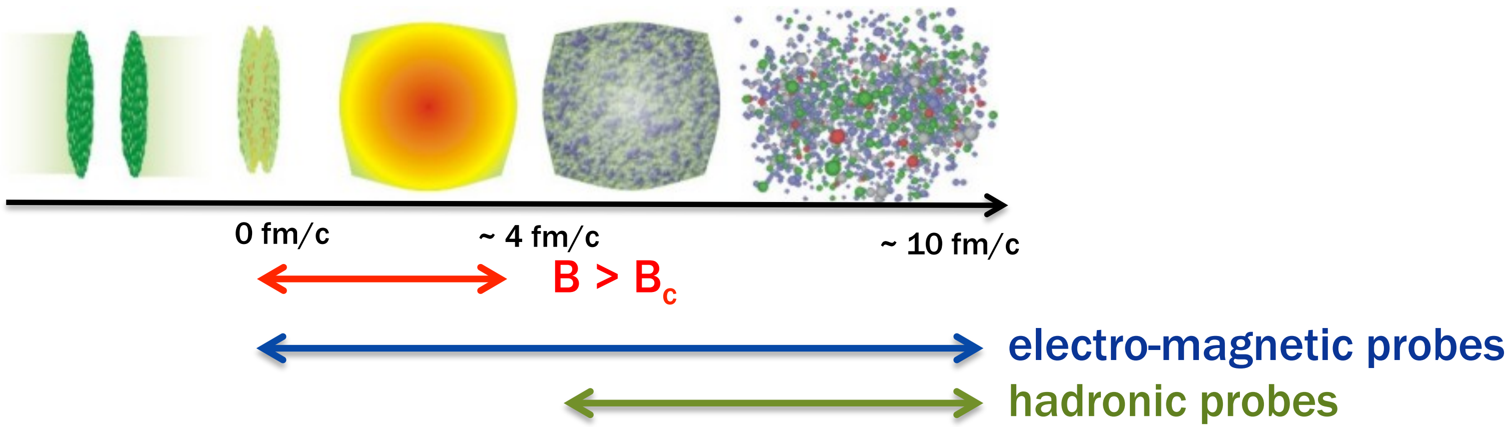


T.Niida for STAR, IS’17

- higher statistics required (and planned) at LHC

Experimental Probes of Intense Field

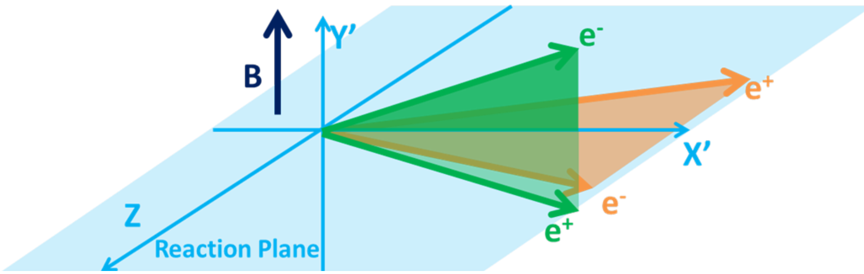
- must originate from initial stages
  - field life time ~ 0.1 fm/c
- must be electro-magnetic

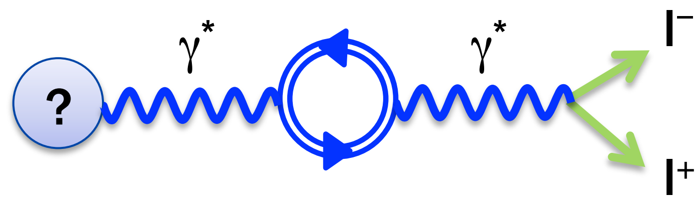


- ideal probe: direct γ/γ^* from pQCD processes
- good reference: γ/γ^* from later stages
  - e.g. π^0 decay γ/γ^* (Dalitz di-electron)

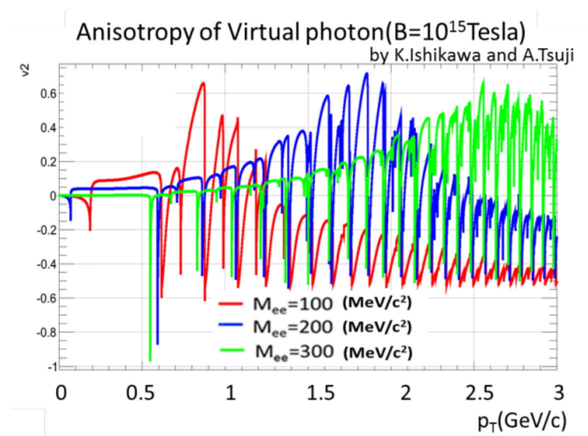
Direct Photon Polarization

- anisotropic decay w.r.t. magnetic field





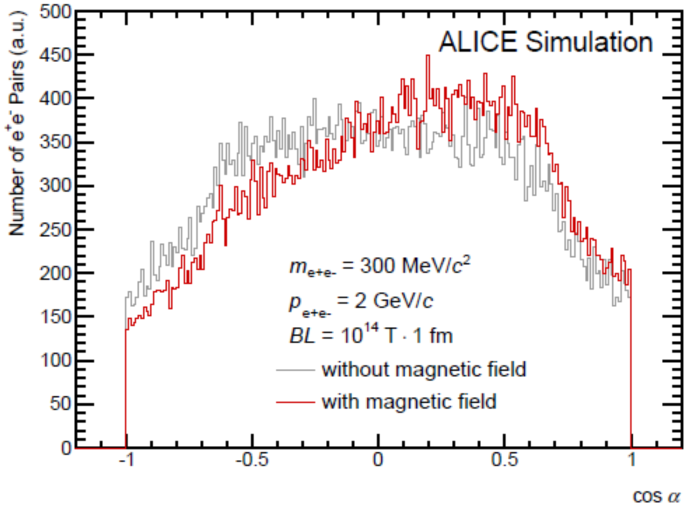
- feasibility study based on QED calculations
  - vacuum polarization tensors under magnetic field
    - summation for infinite Landau levels
    - photon momentum up to ~ GeV
    - *ref.* K.-I. Ishikawa, K. Shigaki, *et al.*, Int. J. Mod. Phys. A28, 1350100 (2013)



- anisotropy ~ $o(10^{-1})$

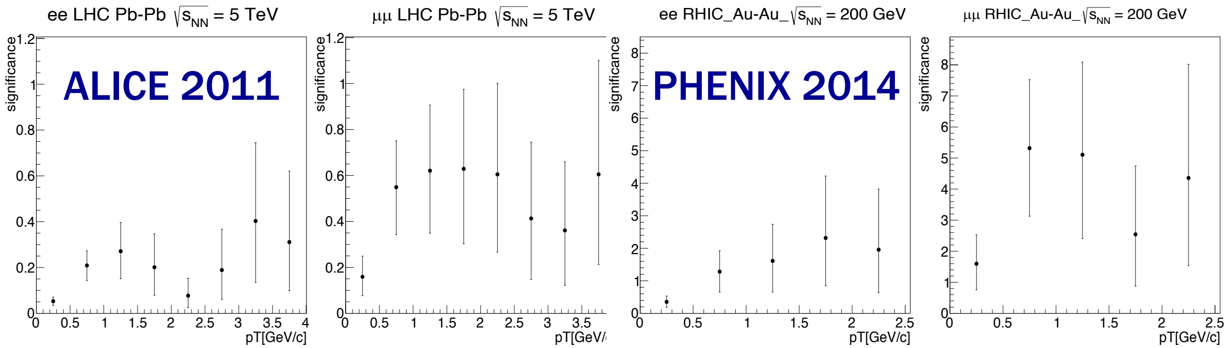
Femto-Spectrometer

- bending power *Bdl* ~ 10^{14} T×10^{-15} m
- → bending angle ~ $3\times10^{-2}/p$ [rad/(GeV/*c*)]
- detectable as opening angle offset
  - e^+/e^- bent in opposite way around magnetic field axis
    - reaction axis from directional flow (v_1) in forward/backward
  - *o*(1) degree for *o*(1) GeV/*c* particles!



Key Issue: Significance, *i.e.* Statistics

- marginal at best, in 2012–2016
  - 4 M.Sc. theses in 2013–2016
    - T.Hoshino, A.Tsuji, R.Tanizaki, Y.Ueda
  - 5 B.Sc. theses in 2012–2015
    - A.Tsuji, R.Tanizaki, Y.Ueda, A.Nobuhiro, K.Yamakawa
- higher statistics data available/coming in
  - 1 B.Sc. thesis in 2018
    - T.Osako



- ALICE run 3 very promising with ×100 stat.

Remarks on Intense Field Search

- wide range of interests; not only LPV/CME(/CVE)
- field time structure: key for physical significance
  - longer-lived participant component in “perfect fluid”?
  - hydro-dynamical model with local charge flow wanted
- proposals of experimental detection approaches
  - seemingly feasible; simulations and real data analysis
    - direct photon polarization
    - femto-spectrometer
- semi-long term visitor, Q. Y. Shou (SIAP, China)
- high prospects in near-future high statistics data
  - both muons and electrons in ALICE run 3 (2021–)

Summary and Concluding Remarks

- muon no longer “forward” probe at LHC
  - electron and muon reunion since fixed target era
    - parallel and complementary probes
- MFT opening new and wide physics windows
  - open heavy flavor, quarkonia, low mass, and continuum
  - covering most (if not all) of whole shopping list
    - even exotics, *e.g.* intense magnetic field search
- time to invest more human resources
  - balance between hardware and physics
  - synergistically collaborating with MFT France
  - effective use of our new grant (JFY’18 - 22)