RHIC & LHC to FAIR

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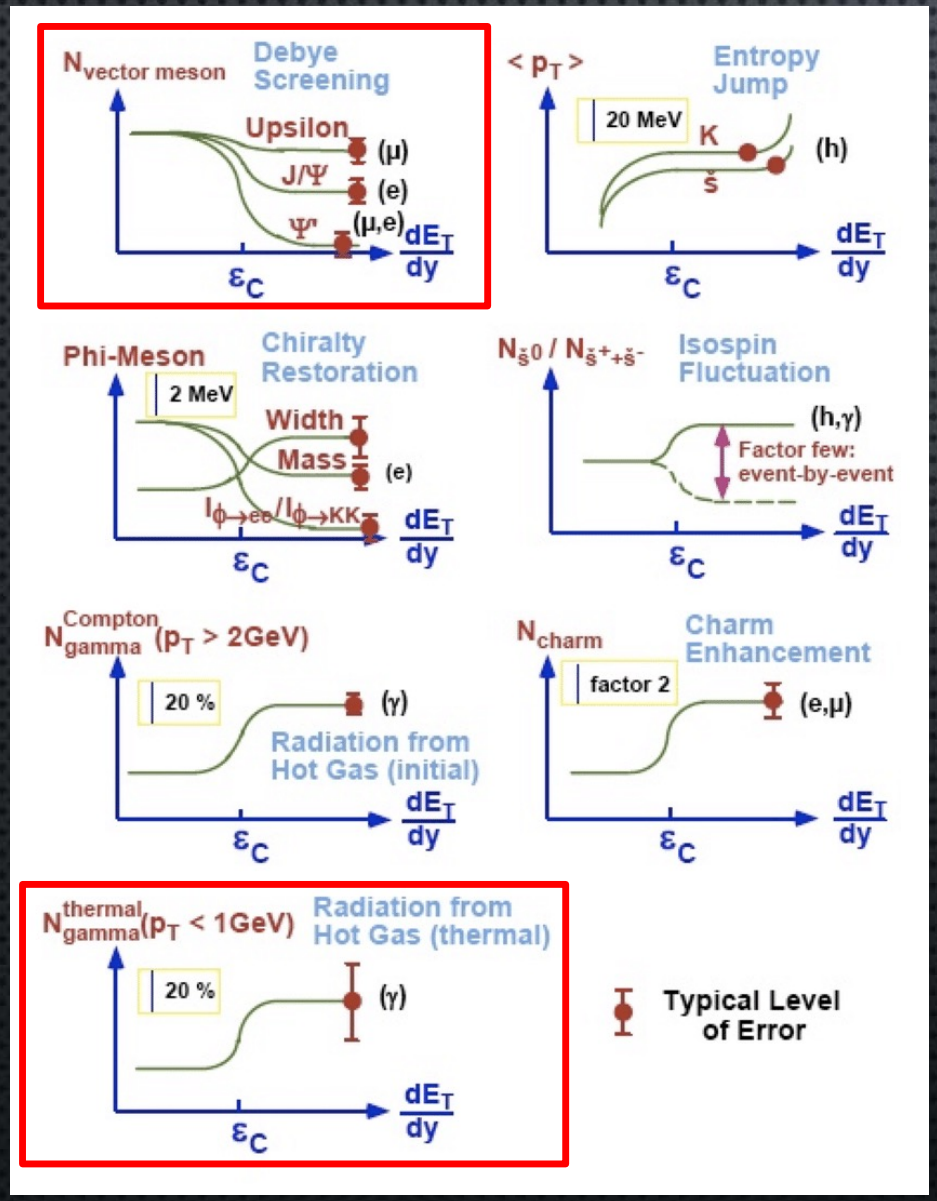
Workshop at Quark-Nuclear Matters in TCHoU

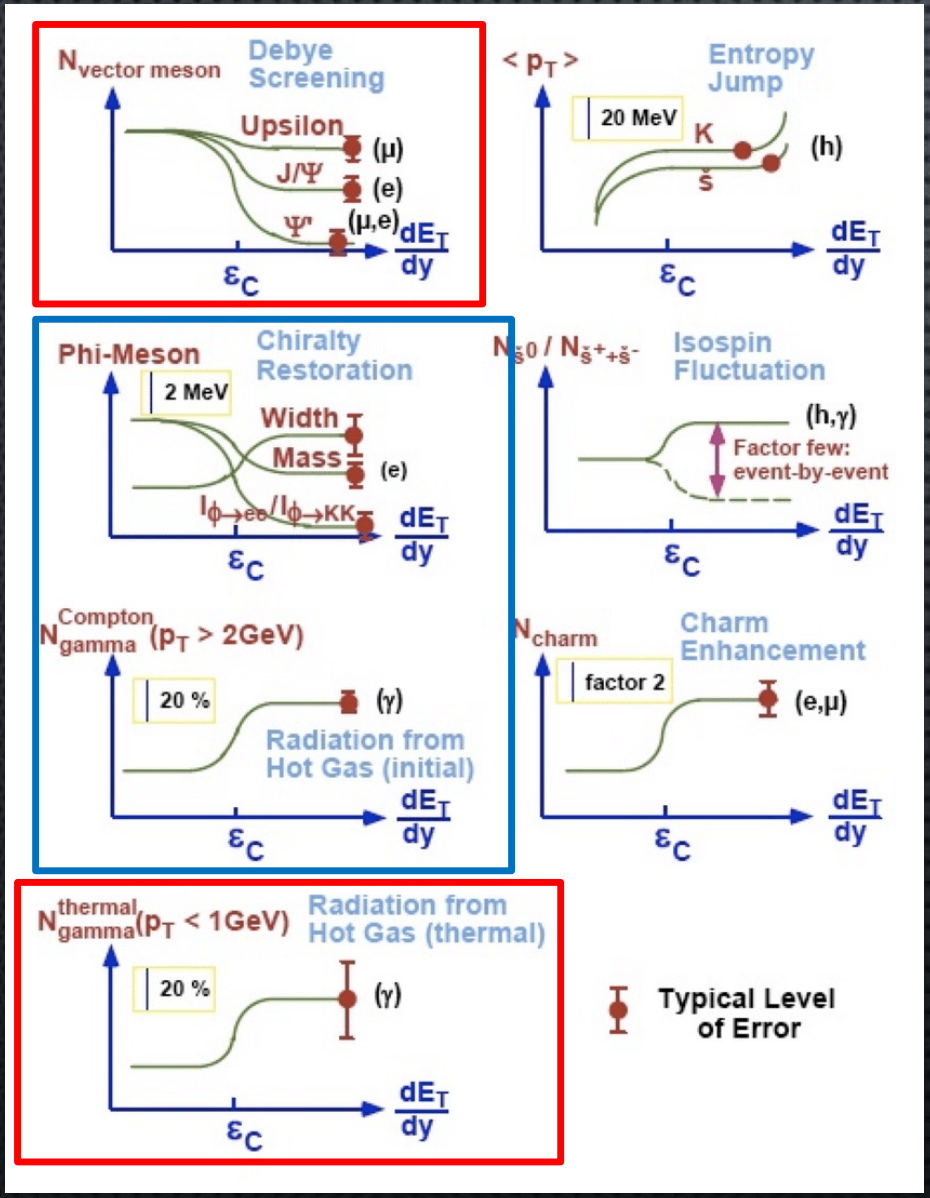
Mar. 29, 2024

Prospects before RHIC & LHC



- Main purpose was:
  - Probing of an existence of Quark Gluon Plasma
  - QGP signatures were observed at RHIC & LHC
    - ✓ J/ψ, Υ suppressions
    - ✓ Thermal photons from the medium
    - ✓ Jet quenching
    - ✓ Collective flow

Prospects before RHIC & LHC



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  - QGP signatures were observed at RHIC & LHC
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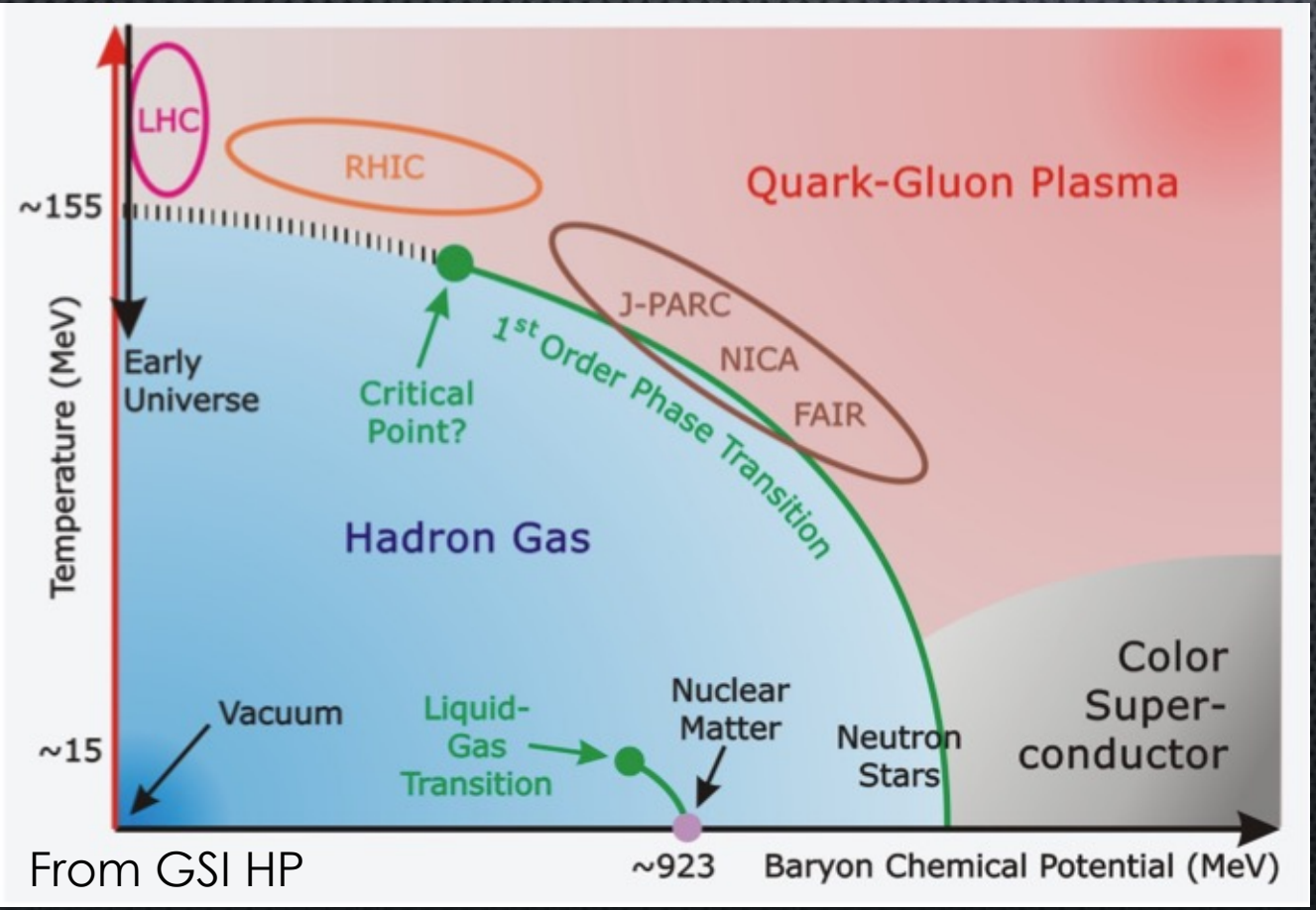
  - But some of important signatures are still missing…

Exploration of QCD phase diagram



From GSI HP

- Large playground in low T & more dense region to be explored
  - NOT just back to AGS energy region
- Interesting topics addressed to future experiments at FAIR, J-PARC-HI
  - ✓ Critical point search
  - ✓ Thermal dileptons
  - ✓ Chiral symmetry restoration
  - ✓ Hyper nuclei
  - ✓ Hadron correlations
  - ✓ Exotic QCD state
  - ✓ …

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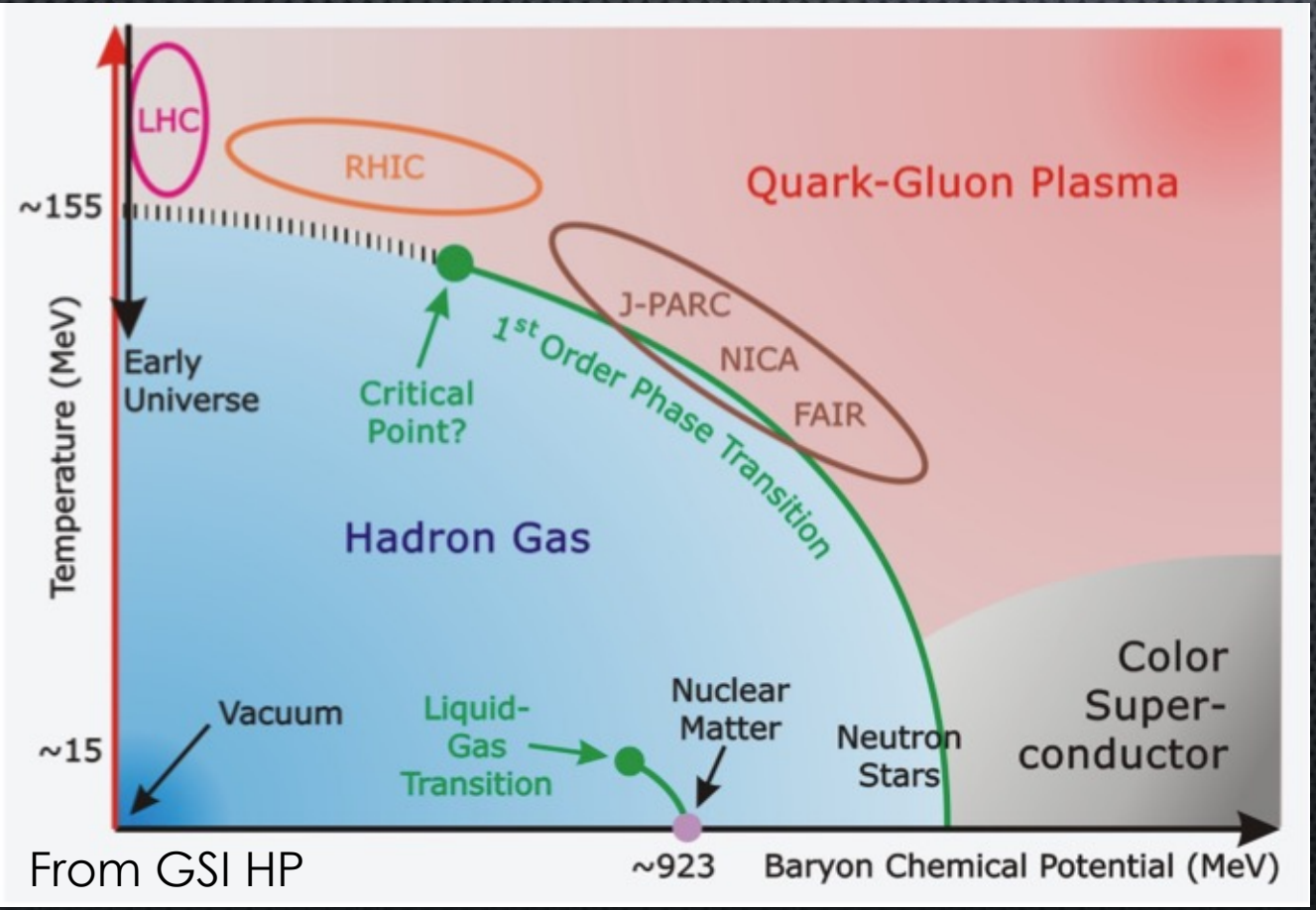

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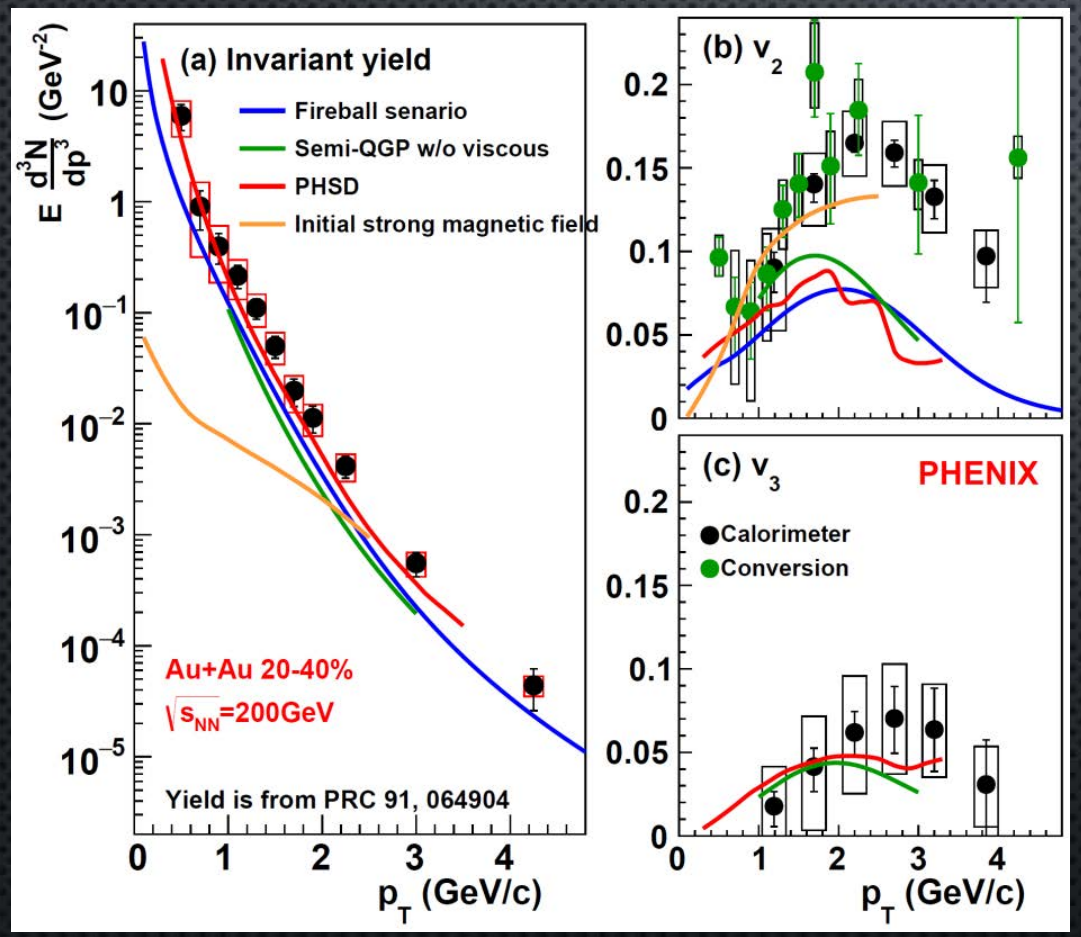
Thermal radiations

PRC94, 064901 (2016)

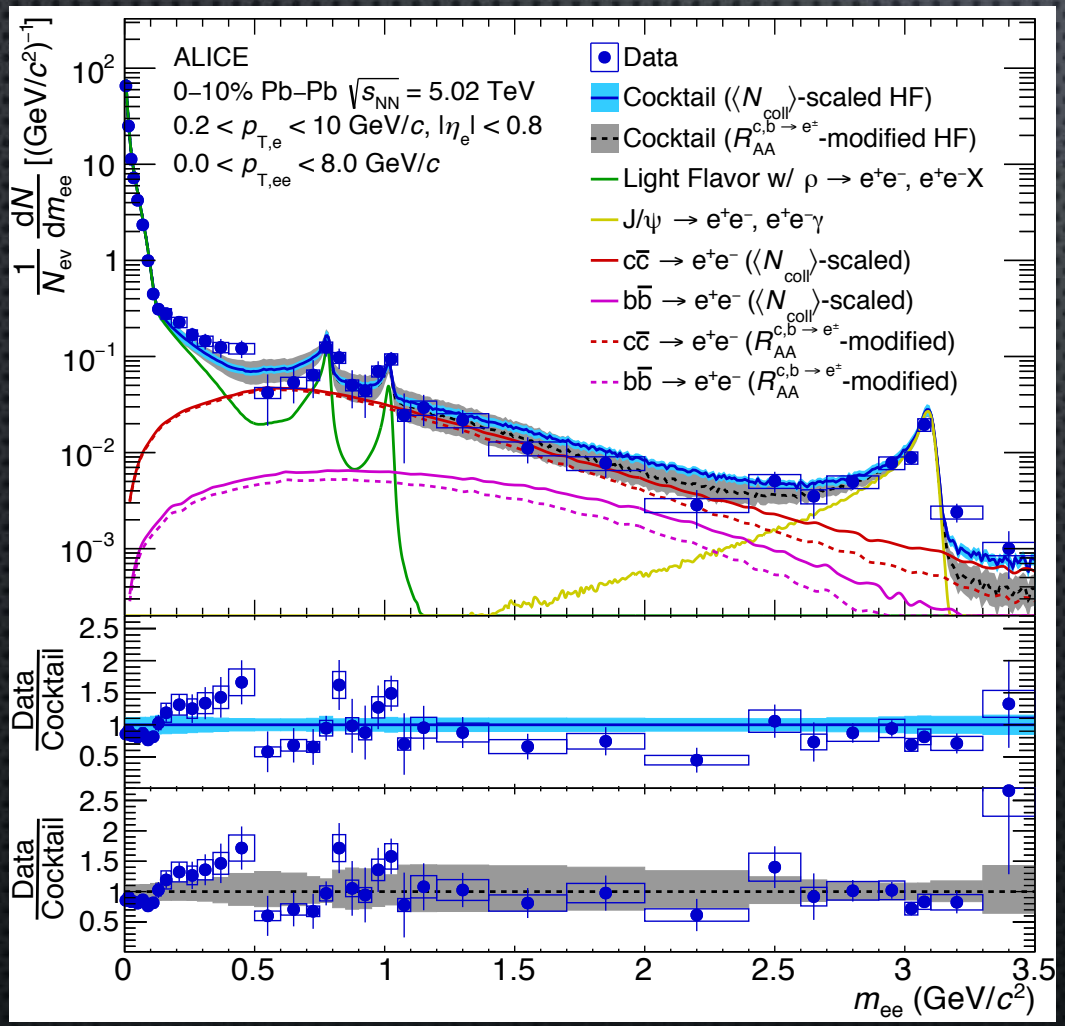


- Thermal photons & dileptons for QGP temperature measurements
  - 1-3 GeV/c photons or 1-3 GeV/c^2 dileptons
- What we've learnt from "direct photon puzzle"
  - Possibly late stage photons are dominant due to bule shift by radial flow
  - Hard to extract initial temperature of the medium from photon spectrum

→ Only solution = thermal dileptons

Thermal dileptons

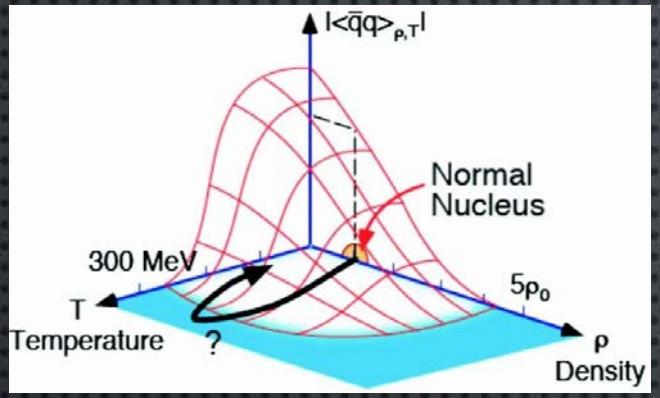
arXiv: 2308.16704 (ALICE)



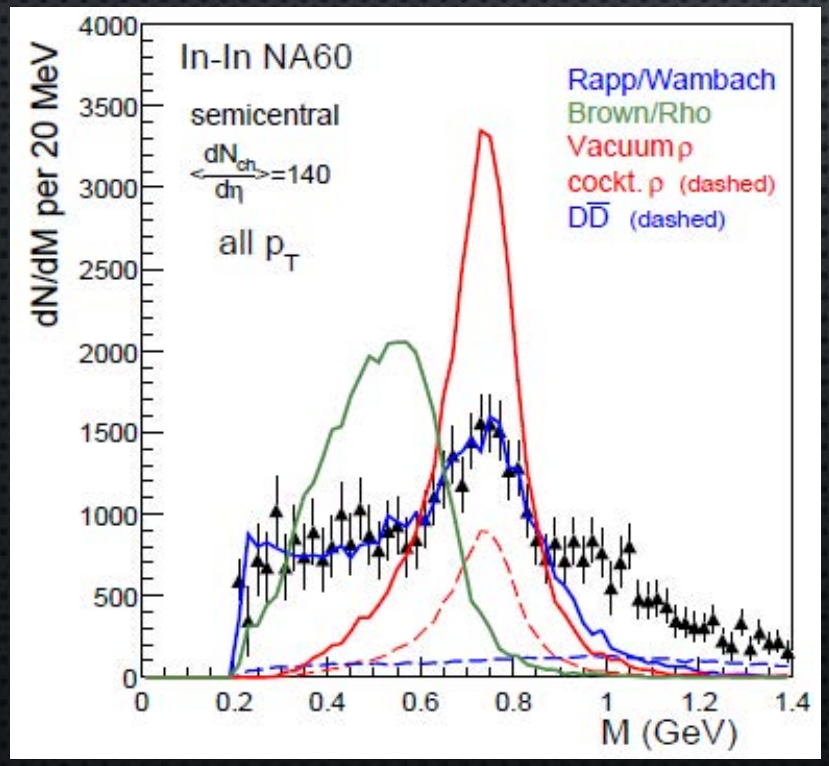
- Only missing EM probe so far
  - Open heavy flavors as dominant background in RHIC & LHC energies
  - Almost free from them at FAIR energy

  → Can be measured if thermalized medium is created

Chiral symmetry restoration



PRL96, 162302 (2006)

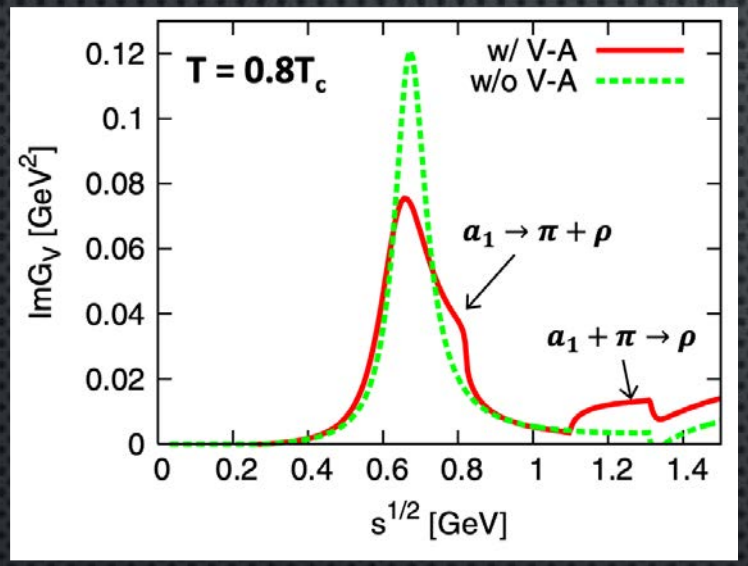


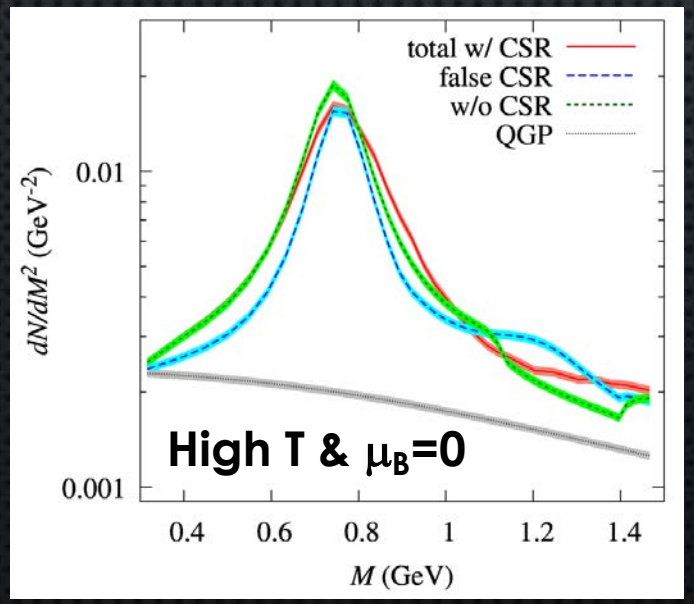
- Hadron mass generation by chiral symmetry breaking
  - Partial restoration in hot and/or high density environment
- Observed positive indications
  - Lower mass tail of ϕ peak for low β at E325 (KEK-PS)
  - Broader ρ peak in In-In at NA60 (SPS)
    - ➢ Better description by broadening due to hadronic effects

→ No conclusive result so far

Chiral mixing

PRD78, 114003 (2008), arXiv: 2308.03305





- What can be conclusive signatures of CSR
  - Degeneracy of mass for chiral partners
  - V-A mixing (ρ-a_1/ω-f_1 mixing)

  → Additional contribution in dilepton spectrum due to Modification of LVM spectral function

- First hydrodynamic calculation w/ CSR
  - Assuming high T & $\mu_B = 0$

  → Moderate enhancement in M>1.1GeV/c^2

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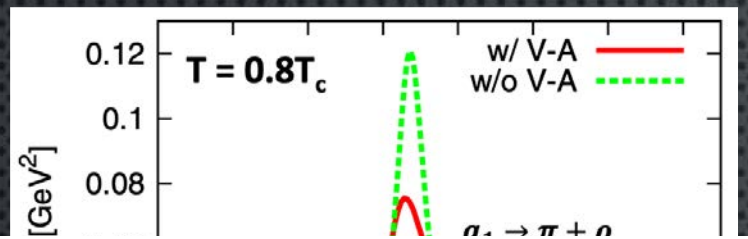

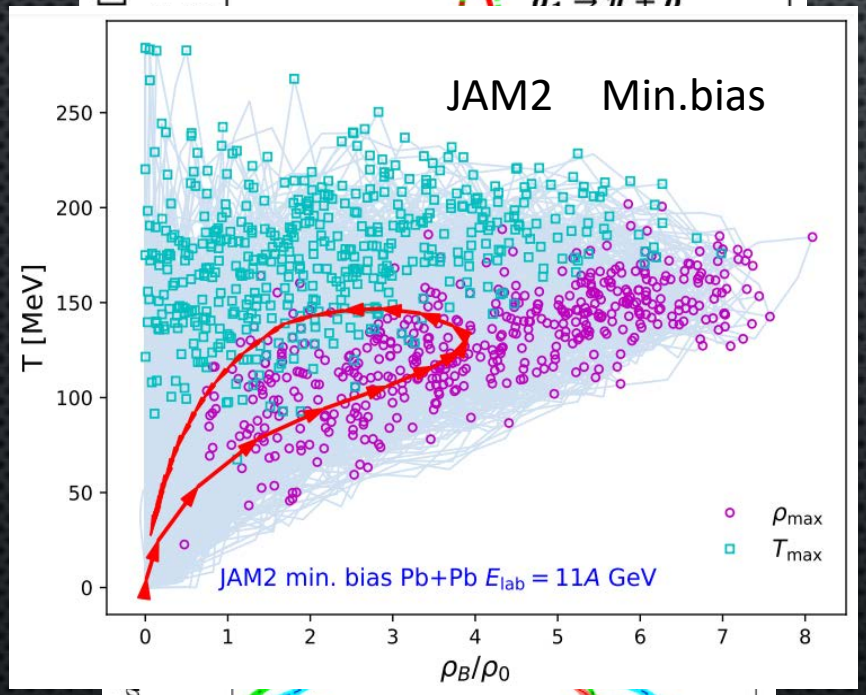

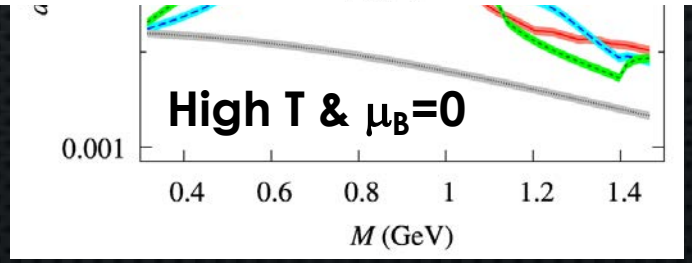

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- First hydrodynamic calculation w/ CSR
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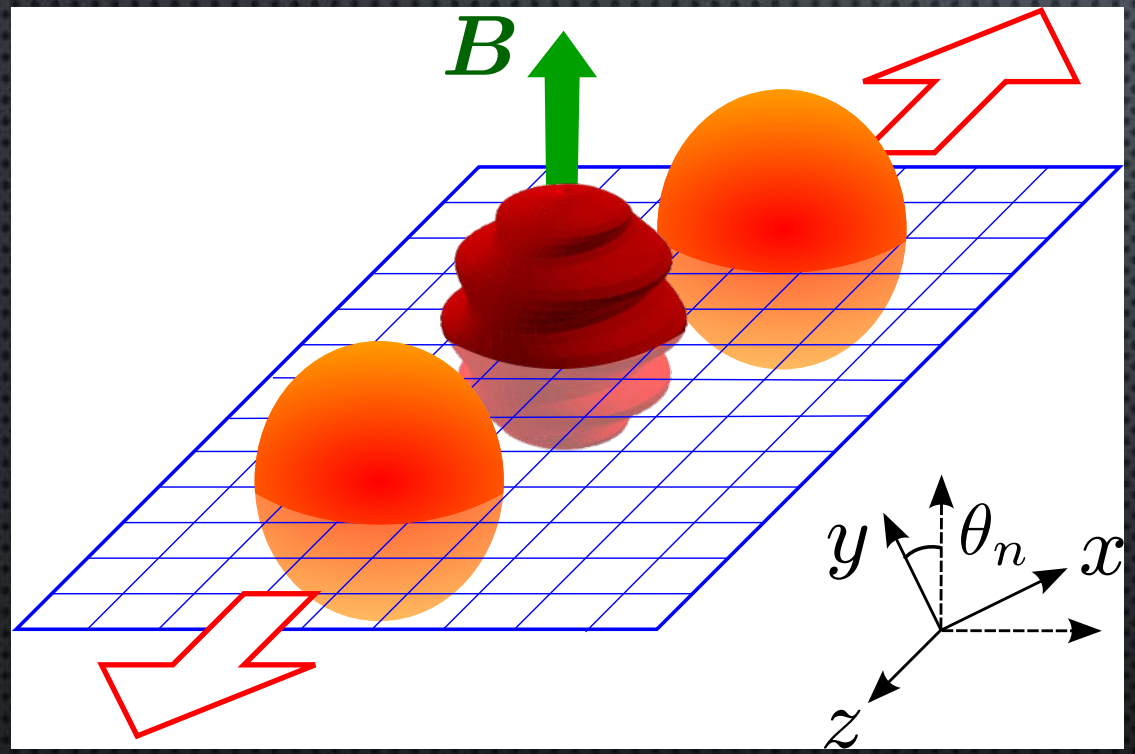
  → Moderate enhancement in M>1.1GeV/c^2
- V-A mixing strength linearly increases with μ_B
  - ref: PRD 106, 054034 (2022)

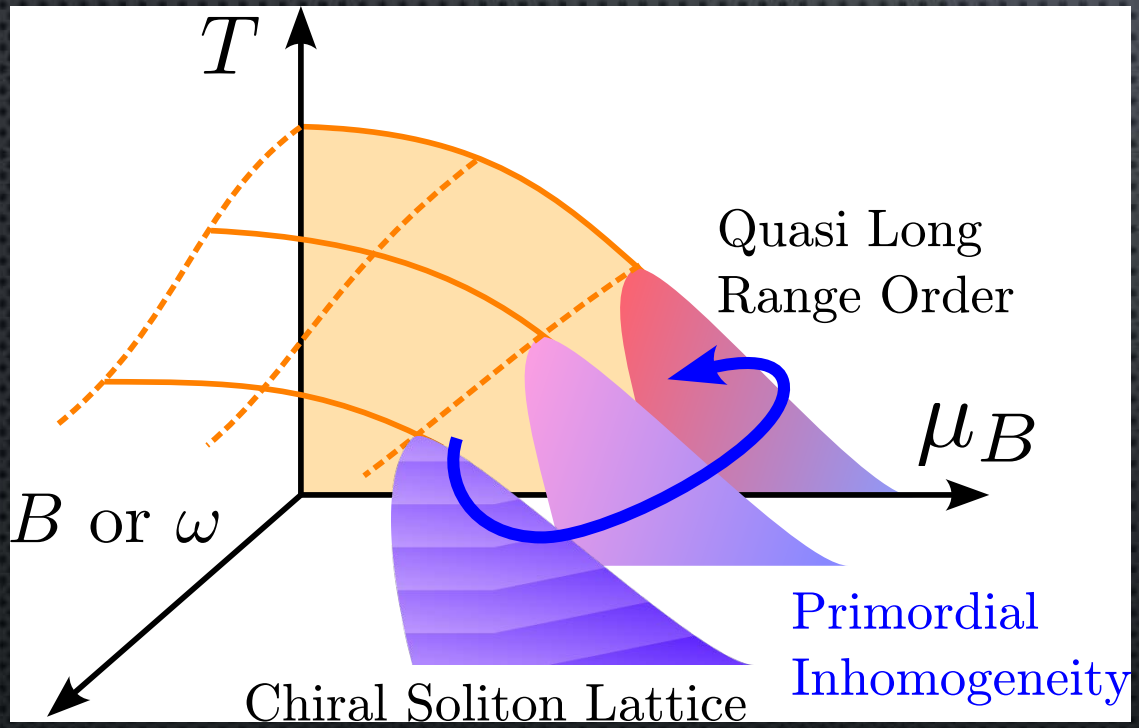
  → Expect stronger signal at FAIR energy

Exotic state in QCD diagram



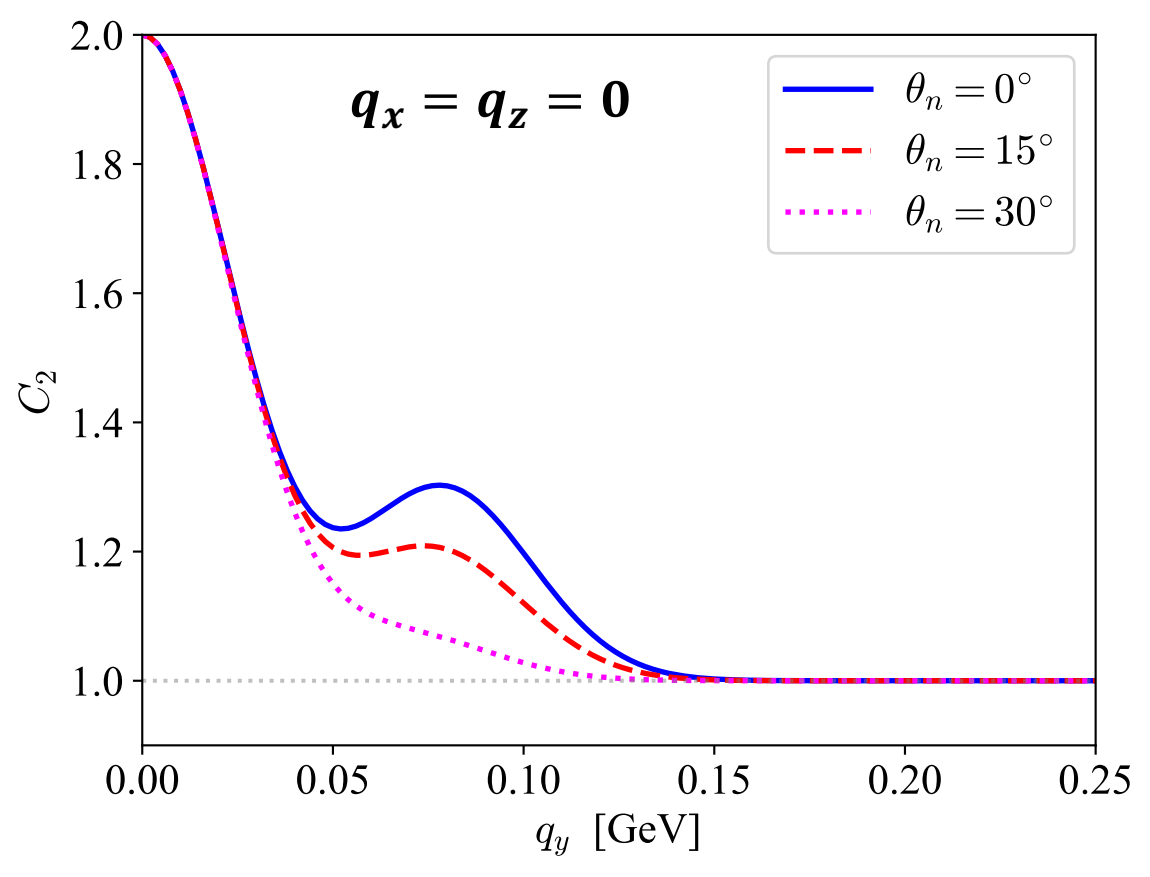
- Emergence of spatial modulation in finite density region predicted by theory
  - Fragile against fluctuations
- External field/fast rotation can assist to realize such inhomogeneity
  - Strong magnetic field with peripheral collision
    - ✓ Chiral Spiral: PRL 104, 232301 (2010)
    - ✓ Chiral Soliton Lattice: JHEP 02, 069 (2018)
- Hot subject in material science as well
  - With same form of Hamiltonian

Primordial inhomogeneity



- Remnant of "primordial inhomogeneity" may survive until freeze-out
  - 1-dimensional inhomogeneity along magnetic field
  - Periodic cluster substructure
    - ✓ Wave number $k \sim 2\mu_q = \frac{2}{3}\mu_B$ from Chiral Spiral
- Proposal of HBT measurement to detect the cluster substructure
  - ➢ arXiv: 2306.17619 (Fukushima, Inoue, Hidaka, Shigaki, Yamaguchi)

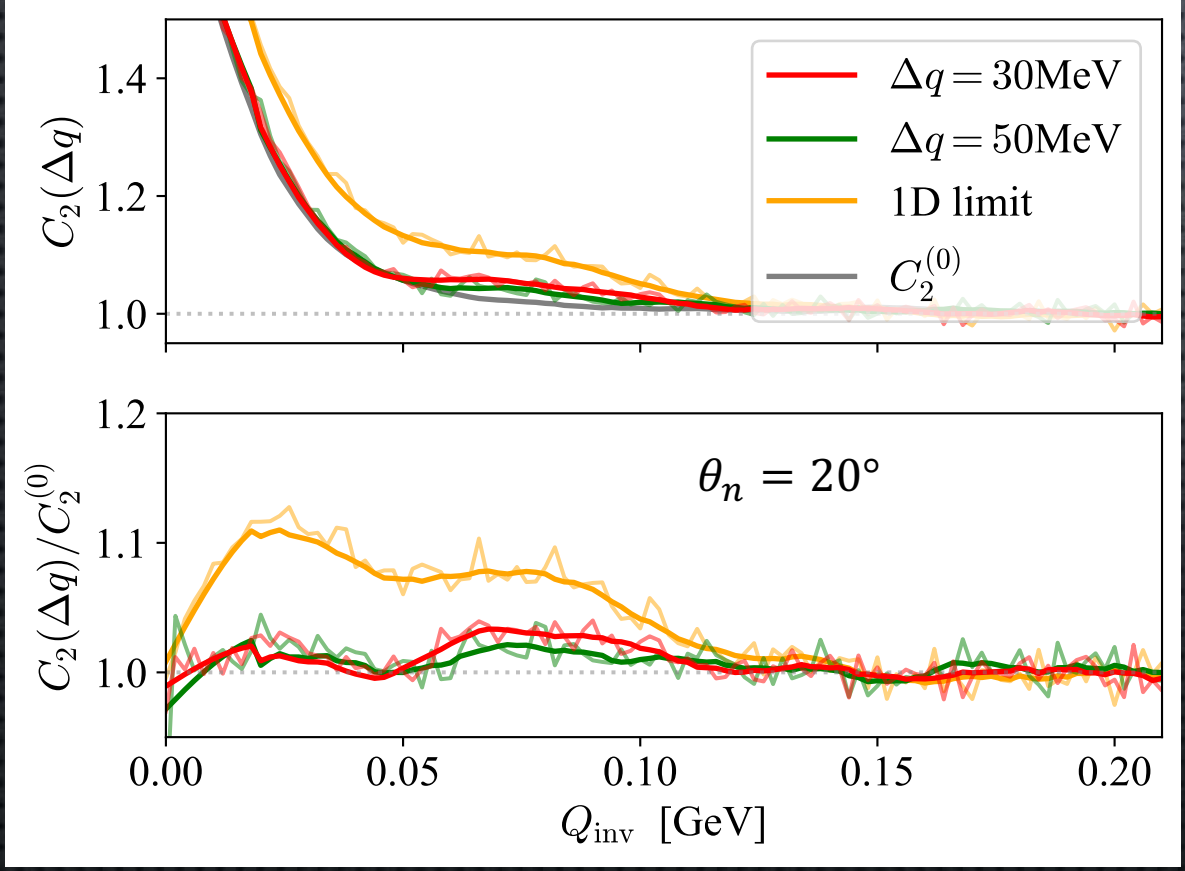
HBT signature of cluster structure



- Demonstration of simple Gaussian source with modulation
  - Gaussian source size $r_0 = 6$fm
  - Wave number $k = 80$MeV for $\sqrt{s_{NN}} = 30$GeV
  - Maximum effect for $\vec{q} \parallel \vec{B}(= \overrightarrow{e_y})$

  → Peak around $k = 80$MeV
- Strong dependence on θ_n
  - θ_n = discrepancy of measured $\vec{B}$ from true $\vec{B}$

Feasibility study



- Feasibility study done with AMPT
  - Impact parameter $b = 3 - 4$fm
  - $\sqrt{s_{NN}} = 39$GeV
  - Modulation by hand, base on AMPT particle distribution
  - $\pi^{\pm} - \pi^{\pm}$ correlation
- Wash-out of signal with large Δq
  - $\Delta q = \sqrt{q_x^2 + q_z^2}$
  - Can serve as baseline

→ Ratio of C_2(small Δq)/C_2(inclusive Δq) helps for signal detection
  - Cancel out systematic errors

Summary

- Exploration of low T & high density region in QCD phase diagram
  - ✓ Based on our current knowledge from RHIC & LHC
- Important/unique topics can be studied at FAIR
  - ✓ Thermal dileptons for initial temperature
  - ✓ V-A mixing signal for chiral symmetry restoration
  - ✓ Search for exotic QCD state by HBT measurement