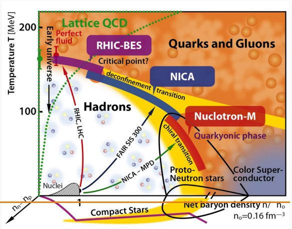
MexNICA: Challenges and opportunities to explore the properties of nuclear matter under extreme conditions



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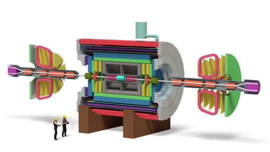
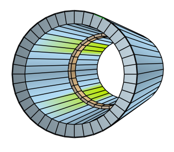
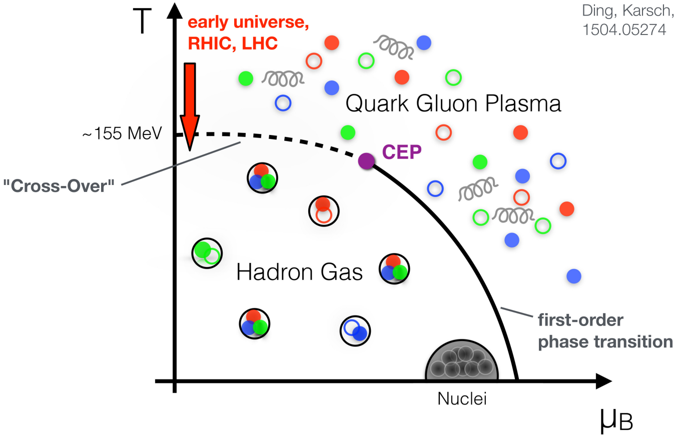




Instituto de Ciencias Nucleares UNAM

Conjectured QCD phase diagram

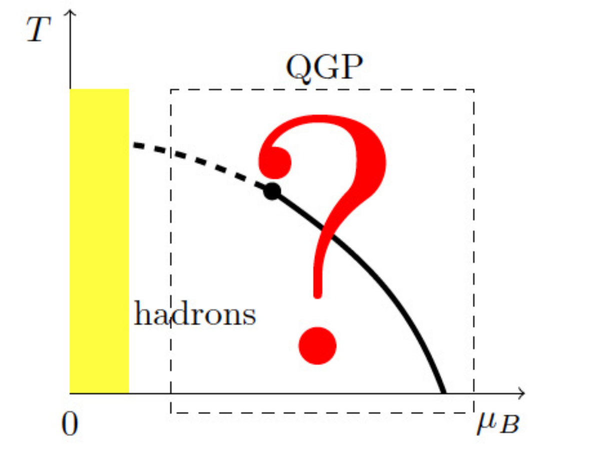
(Conjectured) QCD phase diagram



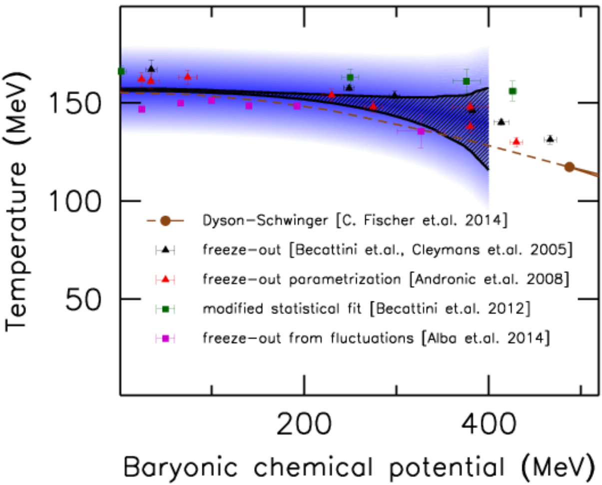
Ding, Karsch, Mukherjee
1504.05274

ultimate goal: contact with first-principles QCD calculations

Phase diagram unknown at large



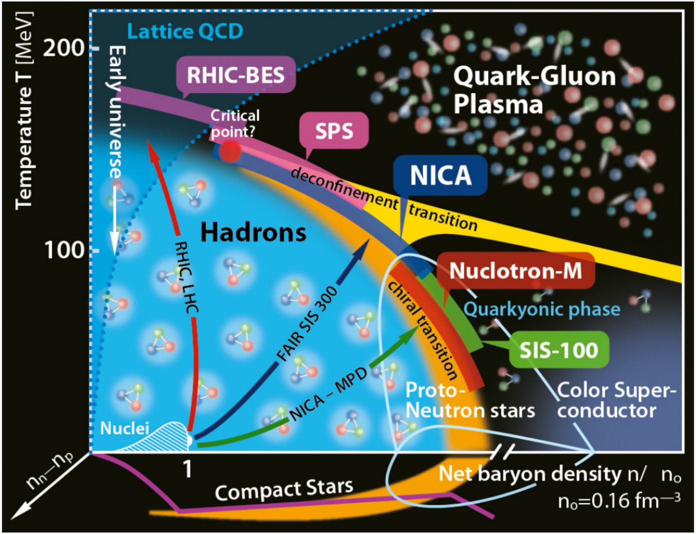
Lattice QCD pseudo-critical transition



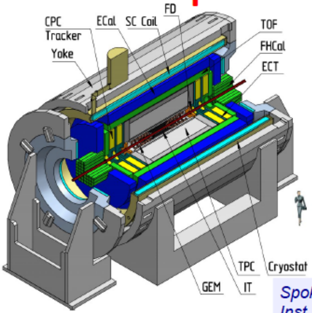
Summary of recent results for the CEP location

Reference	T^{CEP} (MeV)	μ_B^{CEP} (MeV)
C. Shi *et al.*, PRD **93**, 036006 (2016)	$0.85\,T_c$	$1.11\,T_c$
G.A. Contrera *et al.*, EPJA **52**, 231 (2016)	69.9	319.9
S. Sharma, NPA **967**, 728 (2017)	145-155	$> 2\ T^{CEP}$
J. Knaute *et al.*, PLB **778**, 419-425 (2018)	112	204
N.G. Antoniou *et al.*, PRD **97**, 034015 (2018)	119-162	85-86
Z.F. Cui *et al.*, Sci. Rep. **7**, 45937 (2017)	38	345
P. Kovács & G. Wolf, ACP-S **10**, 1107 (2017)		> 133.3
R. Rougemont *et al.*, PRD **96**, 014032 (2017)	< 130	> 133
A. Ayala *et al.*, RMF **64**, 392 (2018)	18-45	315-349

QCD phase diagram NICA



Multi-Purpose Detector (MPD) Collaboration



11 Countries, >500 participants,
39 Institutes and JINR

*AANL, Yerevan, **Armenia;***
*Baku State University, NNRC, **Azerbaijan;***
*University of Plovdiv, **Bulgaria;***
*University Tecnica Federico Santa Maria, Valparaiso, **Chile;***
*Tsinghua University, Beijing, **China;***
*USTC, Hefei, **China;***
*Huzhou University, Huizhou, **China;***
*Institute of Nuclear and Applied Physics, CAS, Shanghai, **China;***
*Central China Normal University, **China;***
*Shandong University, Shandong, **China;***

*Spokesperson: **Adam Kisiel***
*Inst. Board Chair: **Fuqiang Wang***
*Project Manager: **Slava Golovatyuk***

Deputy Spokespersons:
Victor Riabov, Zebo Tang

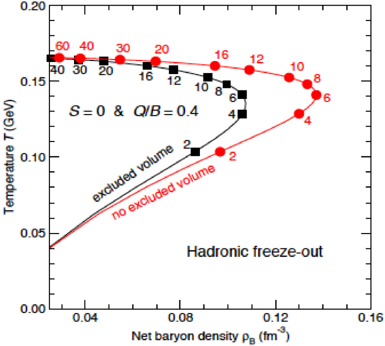
*IHEP, Beijing, **China;***
*University of South China, **China;***
*Three Gorges University, **China;***
*Institute of Modern Physics of CAS, Lanzhou, **China;***
*Palacky University, Olomouc, **Czech Republic;***
*NPI CAS, Rez, **Czech Republic;***
*Tbilisi State University, Tbilisi, **Georgia;***
Joint Institute for Nuclear Research;
*FCFM-BUAP (Mario Rodriguez) Puebla, **Mexico;***
*FC-UCOL (Maria Elena Tejeda), Colima, **Mexico;***
*FCFM-UAS (Isabel Dominguez), Culiacán, **Mexico;***
*ICN-UNAM (Alejandro Ayala), Mexico City, **Mexico;***
*CINVESTAV (Luis Manuel Montaño), Mexico City, **Mexico;***
*Institute of Applied Physics, Chisinev, **Moldova;***
*WUT, Warsaw, **Poland;***
*NCNR, Otwock – Świerk, **Poland;***
*University of Wrocław, **Poland;***
*University of Silesia, **Poland;***
*University of Warsaw, **Poland;***
*Jan Kochanowski University, Kielce, **Poland;***
*Belgorod National Research University, **Russia;***
*INR RAS, Moscow, **Russia;***
*MEPhI, Moscow, **Russia;***
*Moscow Institute of Science and Technology, **Russia;***
*North Osetian State University, **Russia;***
*NRC Kurchatov Institute, ITEP, **Russia;***
*Kurchatov Institute, Moscow, **Russia;***
*St. Petersburg State University, **Russia;***
*SINP, Moscow, **Russia;***
*PNPI, Gatchina, **Russia;***

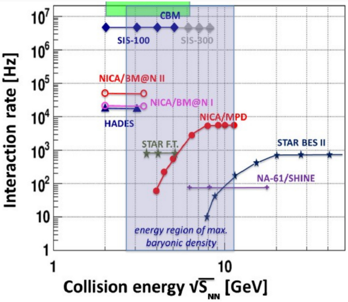
Why HIC at NICA?

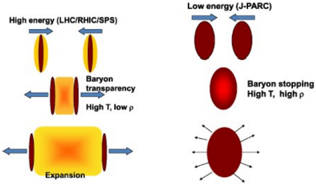
#8: Exploring high-density baryonic matter: Maximum freeze-out density

Jørgen Randrup[1] and Jean Cleymans[2]

Highest baryon density at freeze-out
for $s^{1/2}$~6 GeV, slightly lowering with ex.volume







Transparency vs. Baryon Stopping

NICA-MPD physics

NICA

MPD Physics Programme

1
G. Feofilov, A. Ivashkin

Global observables
- Total event multiplicity
- Total event energy
- Centrality determination
- Total cross-section measurement
- Event plane measurement at all rapidities
- Spectator measurement

2
V. Kolesnikov, Xianglei Zhu

Spectra of light flavor and hypernuclei
- Light flavor spectra
- Hyperons and hypernuclei
- Total particle yields and yield ratios
- Kinematic and chemical properties of the event
- Mapping QCD Phase Diag.

3
K. Mikhailov, A. Taranenko

Correlations and Fluctuations
- Collective flow for hadrons
- Vorticity, Λ polarization
- E-by-E fluctuation of multiplicity, momentum and conserved quantities
- Femtoscopy
- Forward-Backward corr.
- Jet-like correlations

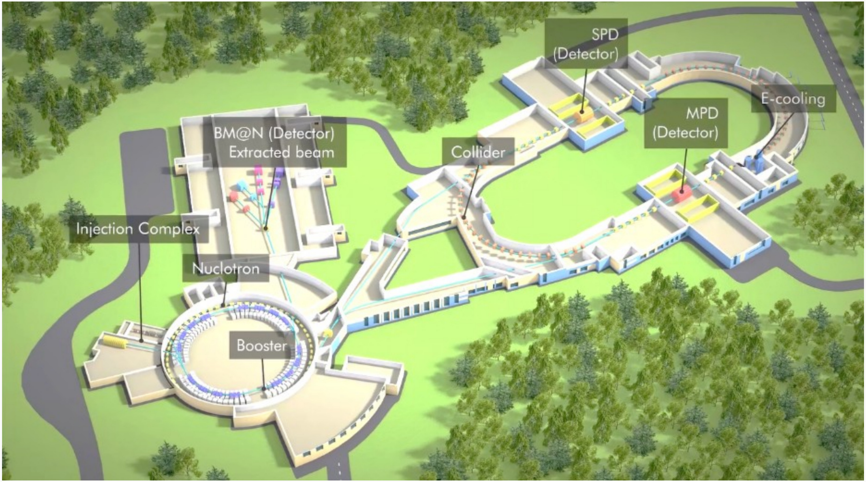
4
V. Riabov, Chi Yang

Electromagnetic probes
- Electromagnetic calorimeter meas.
- Photons in ECAL and central barrel
- Low mass dilepton spectra in-medium modification of resonances and intermediate mass region

5
Wangmei Zha, A. Zinchenko

Heavy flavor
- Study of open charm production
- Charmonium with ECAL and central barrel
- Charmed meson through secondary vertices in ITS and HF electrons
- Explore production at charm threshold

Nuclotron Ion Collider fAcility (NICA)



Civil construction as of September 2020

- Construction of NICA complex in progress
- All technical decisions are taken
- Some design work is finishing
- 6 month of delay due to objective reasons

MPD milestones

NICA Milestones of MPD assembling in 2020-2022

Year 2020

1. July 15th - MPD Hall and pit are ready to store and unpack Yoke parts
2. August - The first 13 plates of Magnet Yoke are assembled for alignment checks
3. Sept 15th - Oct 1st - Solenoid is ready for transportation from ASG (Italy)
4. November 10th - Solenoid is in Dubna
5. Nov-Dec - Assembling of Magnet Yoke and Solenoid at JINR

Year 2021

6. Jan- April - Preparation for switching on the Solenoid (Cryogenics, Power Supply et cet.)
7. May - June - Magnetic Field measurement
8. July - Installation of Support Frame
9. Jul- Dec - Installation of ECal and TOF, Electronics Platform, Cabling

Year 2022

11. Jan- Mar - Installation of TPC, Electronics Platform, Cabling
12. March - Installation of beam pipe, FHCal, Cosmic Ray test system
13. April-Dec - Cosmic Ray tests
14. December - Commissioning

Year 2023

15. **March - Run on the beam**

Why HIC at MPD-NICA with MexNICA?

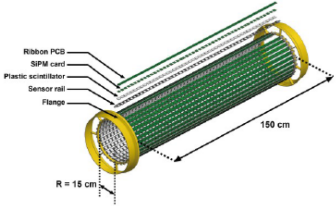
Early MPD involvement allowed for open proposals in missing/complementary coverage: level-0 trigger and beam-monitor by the MexNICA collaboration

- → **Multidisciplinary group:** exp/theory HEP + engineers
- → **Design, construct and operation** of the proposed detectors in MPD
- → **Data taking and analysis** during MPD operation
- → **HEP students+postdocs** in new arenas

Hardware: miniBeBe

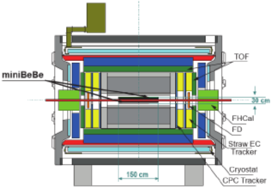
MiniBeBe (Mini Beam-Beam Counter)

MexNICA Collaboration



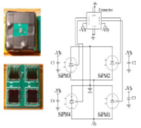
Main requirement:

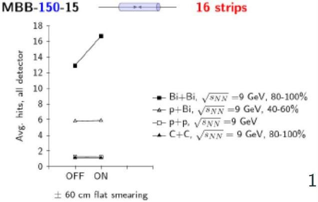
- Provide fast wake-up signal for TOF and reference time for TOF measurement with time resolution of ~30 ps
- Improve trigger efficiency for p+p, p-A and low multiplicity A-A
- Provide possibility to perform luminosity measurements at Phase 0 of NICA operation



Basic cell with four SiPMs & electronics

- 20x20 mm²
- 4 SiPMs card attached to BC404 plastic scintillator
- Fast outputs to "connector" (micro mezzannine)
- DC decoupling capacitors



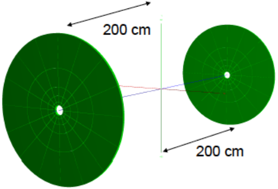


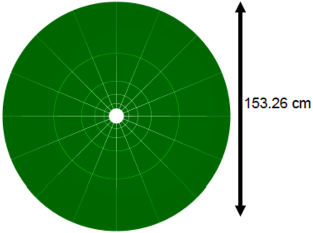
Hardware: BeBe

Detector concept: disk cells

BeBe detector

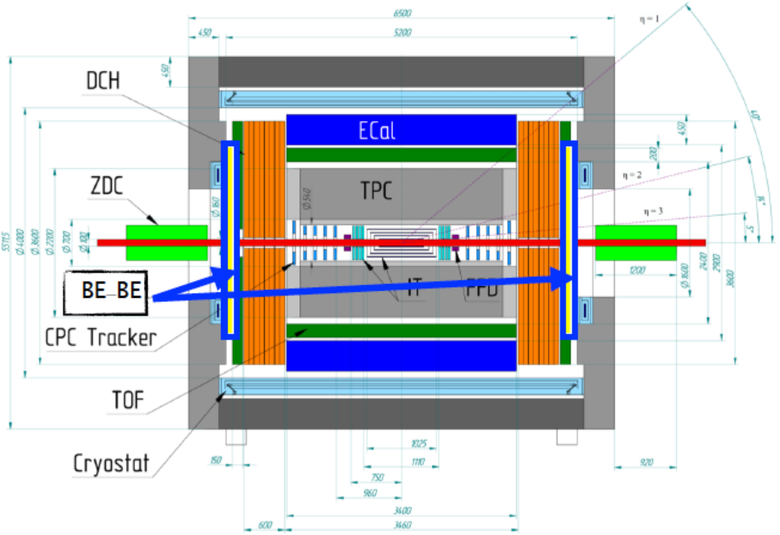
- 80 cells per side (1 cm width)
- five concentric rings
- plastic scintillator BC404
- $1.68 < |\eta| < 4.36$
- photosensors: SiPM or PMT (do be decided)



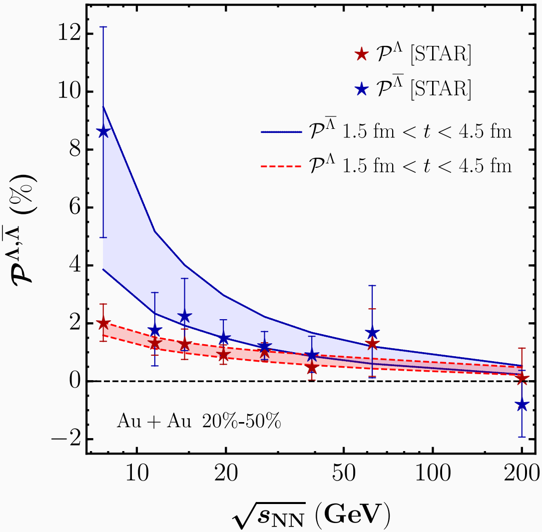


The construction of centrality classes and beam-gas studies with this geometry is a work in progress. A similar physics performance w.r.t. hexagonal geometry is expected.

Hardware: BeBe



$\Lambda/\bar{\Lambda}$ global polarization



Au + Au 20-50% Λ and $\bar{\Lambda}$ polarization from core-corona model bands: Λ and $\bar{\Lambda}$ formation time in QGP range 1.5 fm $< t <$ 4.5 fm

vs

data STAR-BES Nature 548 (2017).

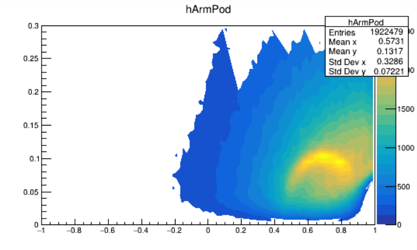
A.A. *et al.*, Phys. Lett. B **810**, 135818 (2020).

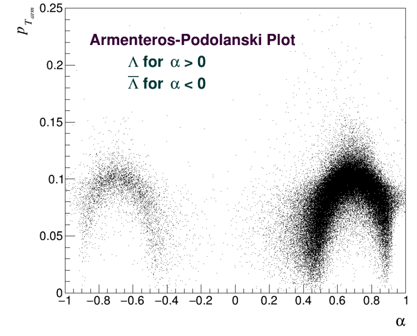
Λ and $\bar{\Lambda}$: MC generation and reconstruction

$$\alpha = \frac{p_L^+ - p_L^-}{p_L^+ + p_L^-}$$

We use:

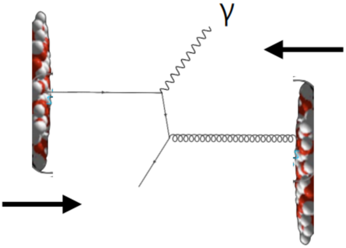
- $\alpha > 0$ for Λ
- $\alpha < 0$ for $\bar{\Lambda}$

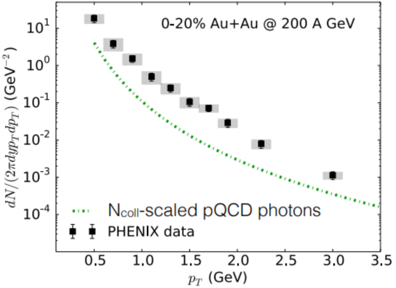




Even with cuts the background is difficult to visualize $\bar{\Lambda}$ $\rightarrow$ we use MC association

Direct photons: prompt + thermal + non-cocktail



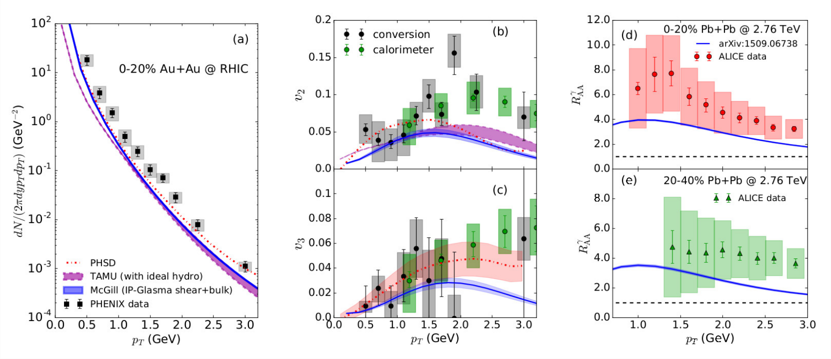


Prompt Photons: Photons produced in the early stages. Quark-Gluon Compton dispersion. Quark-antiquark anihilation. Bremsstrahlung radiation

[C. Shen, U. Heinz, J. -F. Paquet, I. Kozlov, and C. Gale, Phys. Rev. C **91**, 024908 (2015)] 4

Direct photon puzzle

C. Shen, Nucl.Phys. A956 (2016)



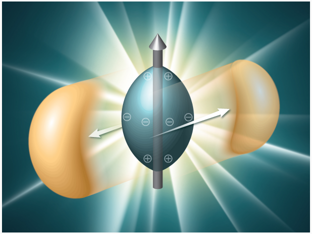
high-p_T photons from hard scattering described NLO pQCD

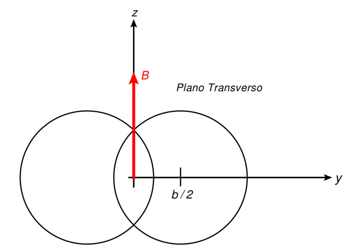
+

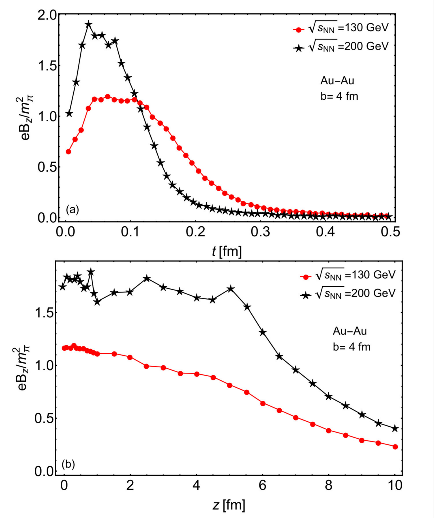
low-p_T photons from thermal emission of the QGP + hadronic phase

Magnetic fields in HICs

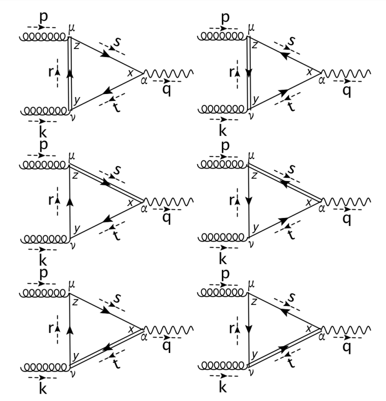
V. Skokov, A.Yu. Illarionov (Trento U.), V. Toneev, Int.J.Mod.Phys. A24 (2009).

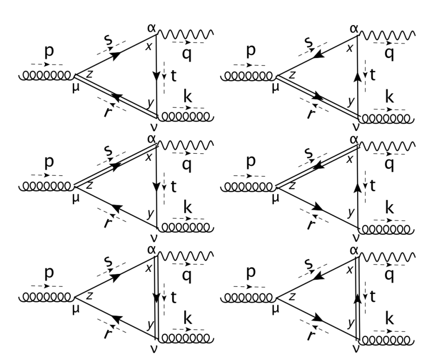


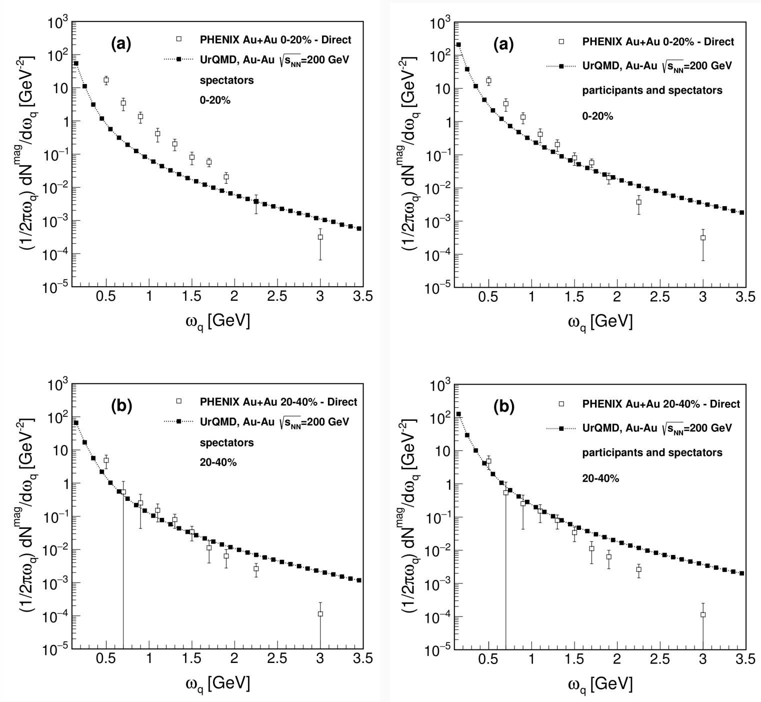




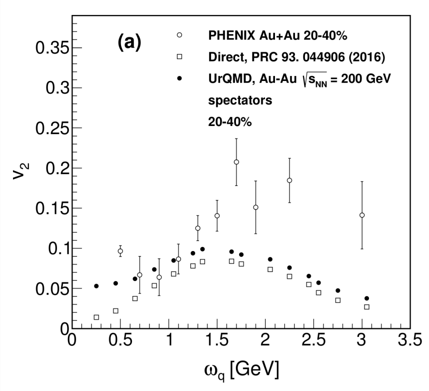
Gluon fusion + splitting + strong magnetic field

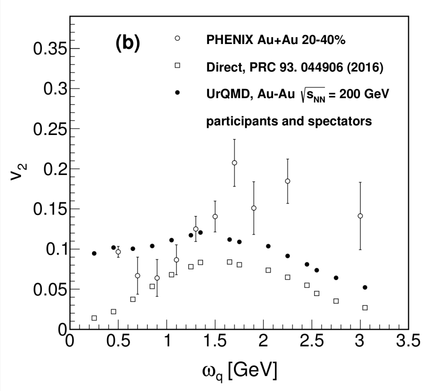





(a)
PHENIX Au+Au 0-20% - Direct
UrQMD, Au-Au $\sqrt{s_{NN}}$=200 GeV
spectators
0-20%
$(1/2\pi\omega_q)\ dN^{mag}/d\omega_q\ [GeV^{-2}]$
ω_q [GeV]
(a)
PHENIX Au+Au 0-20% - Direct
UrQMD, Au-Au $\sqrt{s_{NN}}$=200 GeV
participants and spectators
0-20%
$(1/2\pi\omega_q)\ dN^{mag}/d\omega_q\ [GeV^{-2}]$
ω_q [GeV]
(b)
PHENIX Au+Au 20-40% - Direct
UrQMD, Au-Au $\sqrt{s_{NN}}$=200 GeV
spectators
20-40%
$(1/2\pi\omega_q)\ dN^{mag}/d\omega_q\ [GeV^{-2}]$
ω_q [GeV]
(b)
PHENIX Au+Au 20-40% - Direct
UrQMD, Au-Au $\sqrt{s_{NN}}$=200 GeV
participants and spectators
20-40%
$(1/2\pi\omega_q)\ dN^{mag}/d\omega_q\ [GeV^{-2}]$
ω_q [GeV]

Gluon fusion/splitting + strong magnetic field - v_2

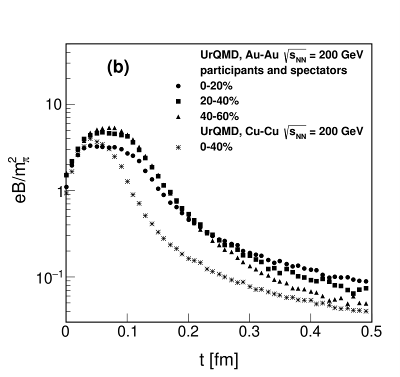


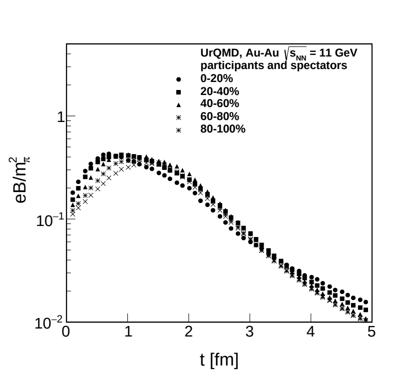


v_2 as a weighted average accounting for magnetic + direct photons

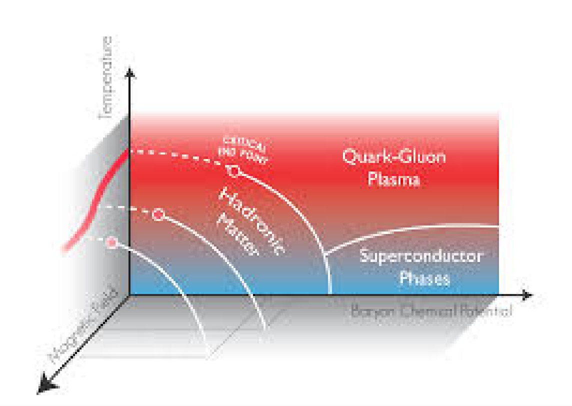
$$v_2(\omega_q) \quad = \quad \frac{\sum_{i=1}^{m} \left[\frac{dN}{d\omega_q}\right]_i [v_2^{\text{mag}}(\omega_q)]_i + \frac{dN^{\text{direct}}}{d\omega_q}(\omega_q)\ v_2^{\text{direct}}(\omega_q)}{\sum_{i=1}^{m} \left[\frac{dN}{d\omega_q}\right]_i + \frac{dN^{\text{direct}}}{d\omega_q}(\omega_q)}$$

UrQMD magnetic field strength as a function of time NICA





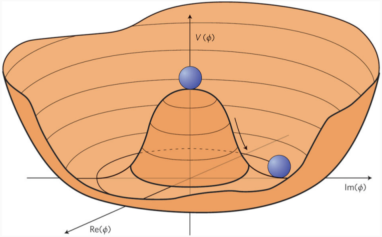
Magnetized phase diagram



Effective QCD model: Linear sigma model with quarks

- Linear sigma model with quarks

$$
\begin{aligned}
\mathcal{L} &= \frac{1}{2}(\partial_\mu \sigma)^2 + \frac{1}{2}(\partial_\mu \vec{\pi})^2 + \frac{a^2}{2}(\sigma^2 + \vec{\pi}^2) - \frac{\lambda}{4}(\sigma^2 + \vec{\pi}^2)^2 \\
&+ i\bar{\psi}\gamma^\mu \partial_\mu \psi - g\bar{\psi}(\sigma + i\gamma_5 \vec{\tau}\cdot\vec{\pi})\psi,
\end{aligned}
$$



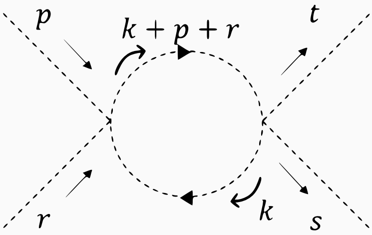
$$
\begin{aligned}
\sigma &\to \sigma + v, \\
m_\sigma^2 &= \frac{3}{4}\lambda v^2 - a^2, \\
m_\pi^2 &= \frac{1}{4}\lambda v^2 - a^2 \\
m_f &= gv \\
v_0 &= \sqrt{\frac{a^2}{\lambda}}
\end{aligned}
$$

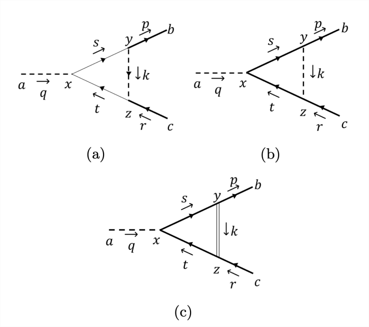
Schwinger proper-time effective potential

$$V_b^{(1)} = \frac{T}{2} \sum_n \int dm_b^2 \int \frac{d^3k}{(2\pi)^3} \int_0^\infty \frac{ds}{\cosh(q_b B s)} e^{-s\left(\omega_n^2 + k_3^2 + k_\perp^2 \frac{\tanh(q_b B s)}{q_b B s} + m_b^2\right)},$$

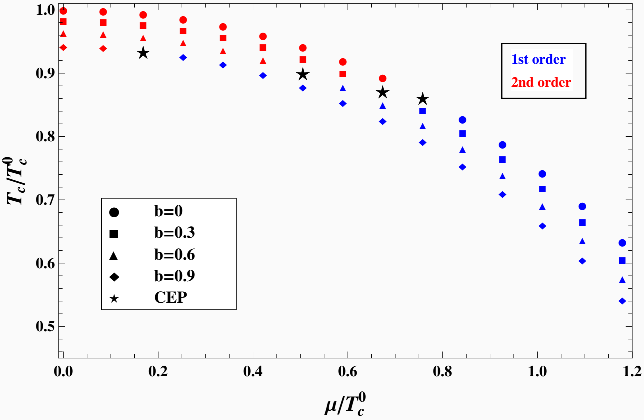
$$V_f^{(1)} = -\sum_{r=\pm 1} T \sum_n \int dm_f^2 \int \frac{d^3k}{(2\pi)^3} \int_0^\infty \frac{ds}{\cosh(q_f B s)} e^{-s\left(\tilde{\omega}_n^2 + k_3^2 + k_\perp^2 \frac{\tanh(q_f B s)}{q_f B s} + m_f^2 + r q_f B\right)}$$

Magnetic field corrected vertices



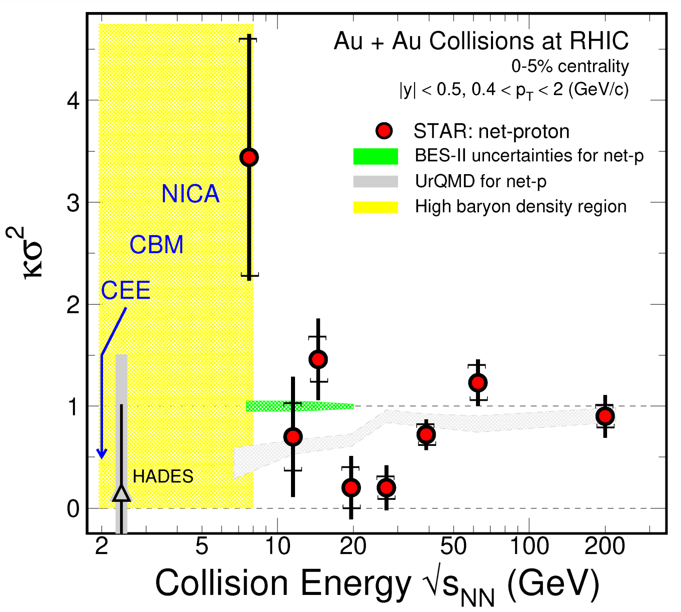


Magnetized phase diagram



A. A., C. Dominguez, L. A. Hernández, M. Loewe, R. Zamora,
Phys. Rev. D **92**, 096011 (2015)

Fluctuations of conserved charges



Final remarks

- The study of strongly interacting matter under **extreme conditions** (Temperature, Baryon Density, Magnetic Fields) is a very active area of research in fundamental physics.
- Field driven by **interplay between theory and experiment.**
- NICA-MPD promises to provide an excellent tool to explore these properties of strongly interactin matter in laboratory conditions.
- **MexNICA** group actively involved **many challenges and opportunities.**

¡GRACIAS!